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Plan of Study - Missouri River Basin Hydrology Study, March 1980.

Symposium Proceedings - Identifying Irrigated Lands Using Remote Sensing Techniques: State of the Art, November 15-16, 1979.

The Missouri River Basin Water Accounting System, September 1981.

Technical Paper - Surface Water Supply Including Instream Water use, February 1982.

Technical Paper - Ground Water Depletions, February 1982.
Appendix II - Transmissivity and Stream Depletion Factor Maps, Platte and Kansas River Basins, Colorado-Kansas-Nebraska-Wyoming.

Technical Paper - Agricultural Water Use Including Identification of Irrigated Lands, September 1982.

Technical Paper - Municipal, Industrial, Energy, and Rural Domestic Water Use, February 1982.

Technical Paper - System Methods and Operations, April 1983.

Users Guide - MRB Water Accounting System.

Missouri River Basin
Hydrology Study
Final Report

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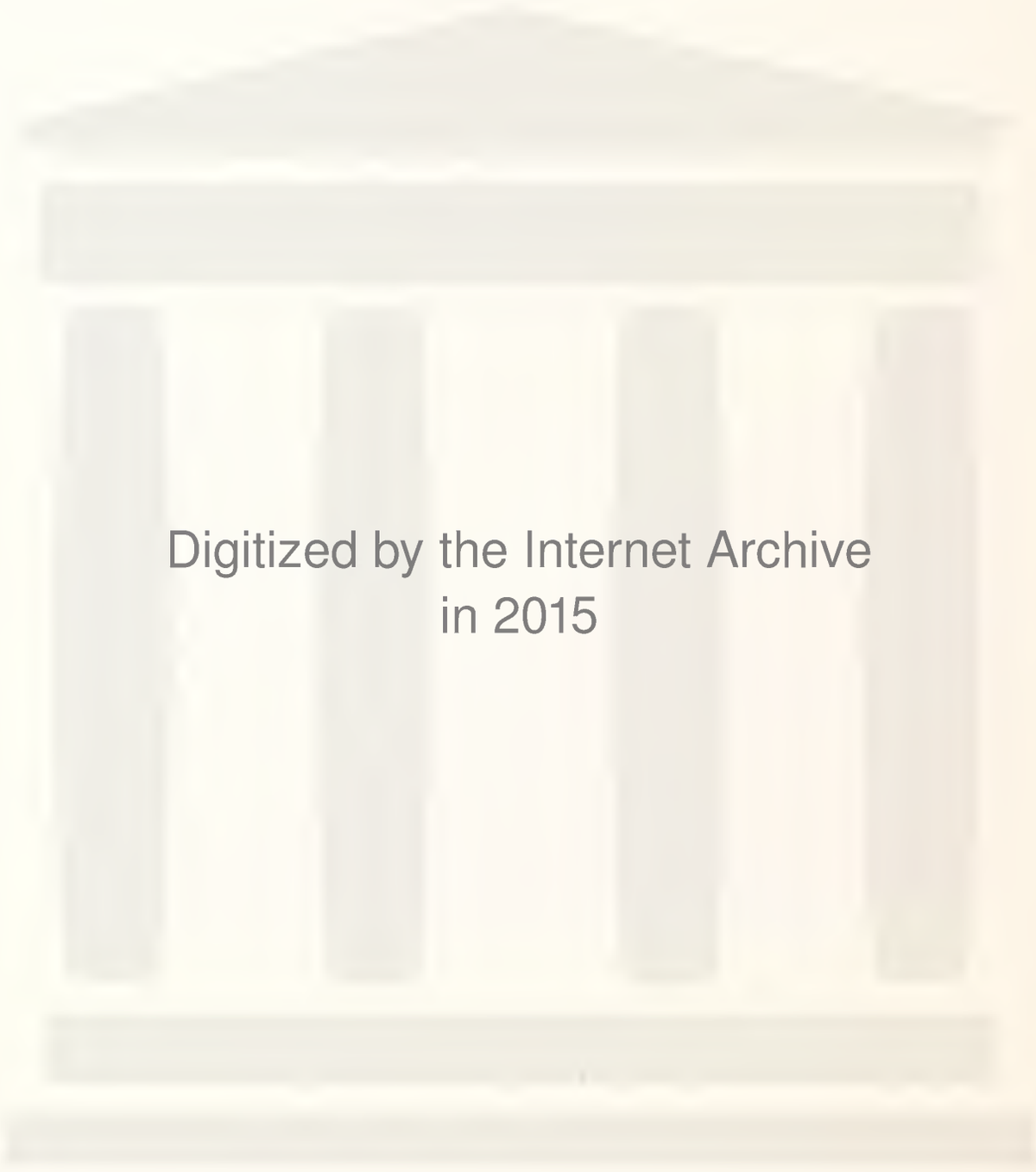
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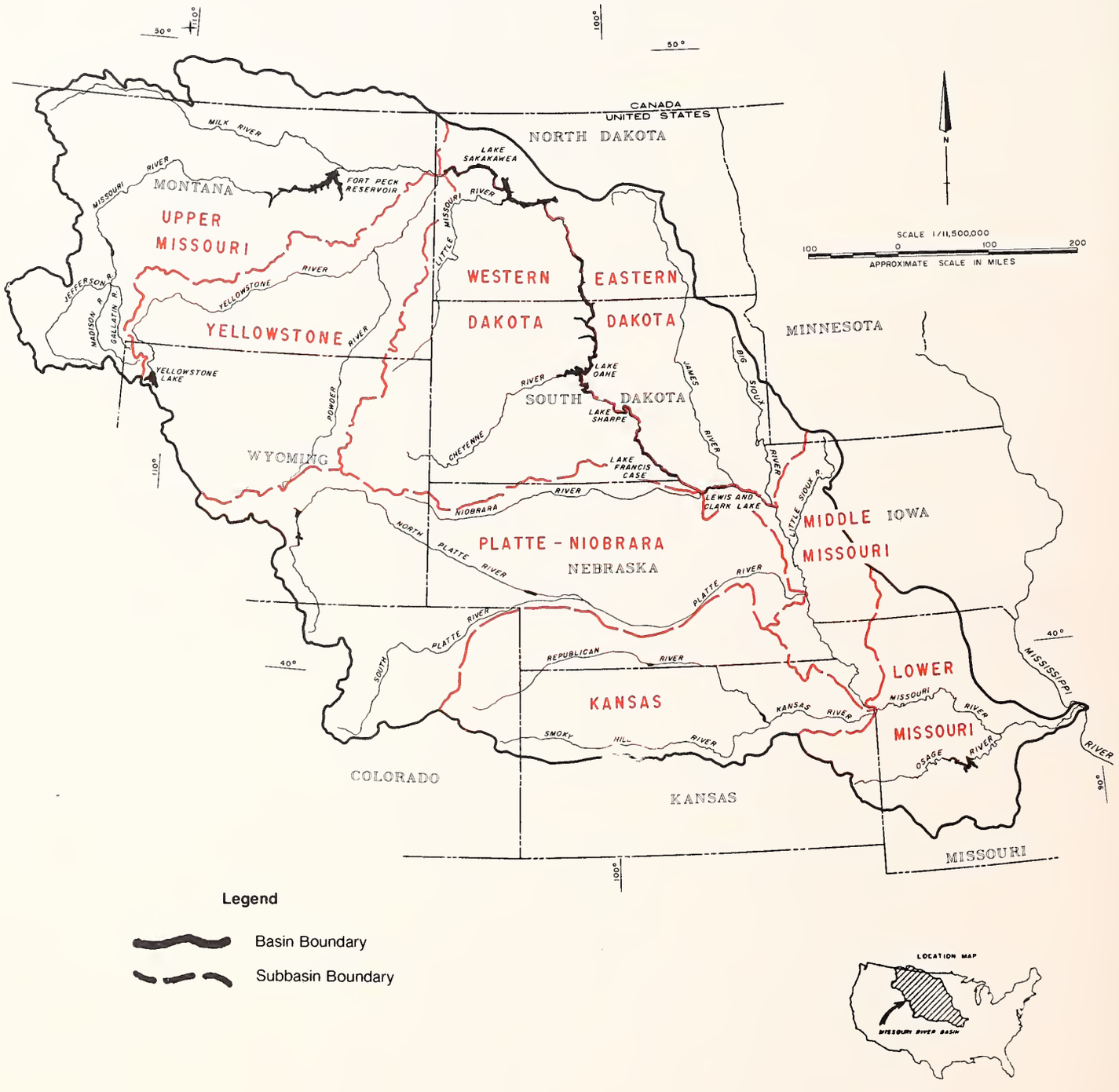
Figure 1
Missouri River Basin Study Area



SUMMARY

The study area included all of the Missouri River basin drainage in the United States (Figure 1). The area covers all of the State of Nebraska; most of Montana, North Dakota, South Dakota and Wyoming; about half of Kansas and Missouri; and smaller parts of Colorado, Iowa and Minnesota; this area drains about 328.5 million acres within the United States. The 6.2 million acres within southern Alberta and Saskatchewan provinces in Canada were not included in this study.

For this study, the Missouri River basin was subdivided into 93 subareas or node basins (Table 1).

Table 1
Node Basins

Node Station Location	Node No.	USGS Gage	Subbasin	Node States
Missouri River @ Toston, MT	020002	054500	UM	MT WY
Missouri River @ Fort Benton, MT	030102	090800	UM	MT
Missouri River below Holter Dam near Wolf Creek, MT	030101	066500	UM	MT
Marias River near Chester, MT	030201	101500	UM	MT
Missouri River below Fort Peck Dam, MT	040101	132000	UM	MT
Musselshell River @ Mosby, MT	040202	130500	UM	MT
Milk River @ Nashua, MT	050002	174500	UM	MT
Milk River @ Eastern Crossing of Int'l Boundary	050003	135000	UM	MT
Missouri River @ Culbertson, MT	060002	185500	UM	MT ND
Yellowstone River @ Billings, MT	070002	214500	YS	MT WY
Yellowstone River @ Corwin Springs, MT	070003	191500	YS	MT WY
Bighorn River @ Bighorn, MT	080012	294700	YS	MT WY
Bighorn River near St. Xavier, MT	080011	287000	YS	MT WY
Wind River below Roysen Reservoir, WY	080021	259000	YS	WY
Bighorn River @ Kane, WY	080022	279500	YS	WY
Shoshone River below Buffalo Bill Reservoir, WY	080031	282000	YS	WY
Tongue River @ Miles City, MT	090102	308500	YS	MT WY
Tongue River @ stateline near Decker, MT	090103	306300	YS	MT WY
Powder River near Locate, MT	090202	326500	YS	MT WY
Powder River @ Moorhead, MT	090203	324500	YS	MT WY
Yellowstone River near Sidney, MT	100002	329500	YS	MT ND
Missouri River @ Garrison Dam, ND	110101	338490	WD	MT ND
Little Missouri River near Watford City, ND	110202	337000	WD	MT ND
Little Missouri River @ Marmarth, ND	110203	335500	WD	MT WY ND
Cheyenne River @ Cherry Creek, SD	120102	439300	WD	SD WY NE
Cheyenne River @ Edgemont, SD	120103	395000	WD	WY SD
Belle Fourche River near Elm Springs, SD	120202	438000	WD	MT WY SD
Belle Fourche River @ WY-SD stateline	120203	428500	WD	WY
Belle Fourche River below Keyhol Dam, WY	120201	427500	WD	WY
Missouri River @ Oahe Dam, SD	130101	2*	WD	ND SD
Knife River @ Hazen, ND	130212	340500	WD	ND
Heart River near Mandan, ND	130222	349000	WD	ND
Cannonball River @ Breien, ND	130232	354000	WD	ND SD
Grand River @ Little Eagle, SD	130312	357800	WD	SD ND
Moreau River near Whitehorse, SD	130322	360500	WD	SD
Missouri River @ Fort Randall Dam, SD	140111	453000	WD	SD
Missouri River @ Big Bend Dam, SD	140121	3*	WD	SD
Bad River Near Fort Pierre, S.D.	140102	441500	WD	SD
White River near Oacoma, SD	140202	452000	WD	SD NE
Niobrara River near Spencer, NE	150002	465000	PN	WY NE SD

Continued page 2

Table 1, Continued

James River near Scotland, SD	160002	478500	ED	ND SD
James River @ La Moure, ND	160003	470500	ED	ND
Vermillion River near Wakonda, SD	170122	479000	ED	SD
Missouri River @ Yankton, SD	170101	467500	ED	SD NE
Big Sioux River @ Akron, IA	170202	485500	ED	SD MN IA
North Platte River @ North Platte, NE	180002	693000	PN	NE
North Platte River @ Kingsley Dam, NE	180011	5*	PN	WY NE
North Platte River @ WY-NE stateline	180013	674500	PN	WY CO
North Platte River below Guernsey Reservoir, WY	180021	656000	PN	WY
North Platte River @ Alcova, WY	180031	642000	PN	WY CO
Laramie River and Pioneer Canal near Woods, WY	180023	659500	PN	WY CO
North Platte River near Northgate, CO	180033	620000	PN	CO
South Platte River @ North Platte, NE	190012	765500	PN	CO NE
South Platte River @ Julesburg, CO	190003	764000	PN	WY CO NE
South Platte River @ Balzac, CO	190022	760000	PN	CO WY
South Platte River @ Henderson, CO	190032	720500	PN	CO
Platte River near Duncan, NE	200102	774000	PN	NE
Platte River @ Louisville, NE	200202	805500	PN	NE
Loup River @ Columbus, NE	210002	794500	PN	NE
Elkhorn River @ Waterloo, NE	220002	800500	PN	NE
Missouri River @ Omaha, NE	230012	610000	MM	IA NE
Little Sioux River near Turin, IA	230022	607500	MM	MN IA
Missouri River @ Sioux City, IA	230032	486000	ED	SD NE IA
Missouri River @ St. Joseph, MO	240012	818000	MM	IA MO NE KS
Nodaway River near Burlington Jct., MO	240013	817500	MM	IA MO
Nishnabotna River above Hamburg, IA	240023	810000	MM	IA
Missouri River @ Nebraska City, NE	240022	807000	MM	NE IA
Republican River below Milford Dam, KS	250011	857100	KR	KS NE
Republican River near Hardy, NE	250013	853500	KR	KS NE
Republican River below Harlan County Dam, NE	250021	849500	KR	CO KS NE
North Fork Republican River @ CO-NE stateline	250023	823000	KR	CO
Arikaree River @ Haigler, NE	250033	821500	KR	CO KS NE
South Fork Republican River near Hale, CO	250043	826500	KR	CO
Smoky Hill River @ Enterprise, KS	260002	877600	KR	CO KS
Solomon River near Glen Elder, KS	260011	875900	KR	KS
Saline River @ Wilson Dam, KS	260021	868200	KR	KS
Kansas River @ DeSoto, KS	270102	892350	KR	KS
Delaware River below Perry Dam, KS	270101	890900	KR	KS
Big Blue River near Manhattan, KS	270201	887000	KR	KS NE
Big Blue River @ Barneston, NE	270213	882000	KR	NE
Little Blue River near Fairbury, NE	270223	884000	KR	NE KS
Grand River near Sumner, MO	280102	902000	LM	IA MO
Chariton River near Prairie Hill, MO	280202	905500	LM	IA MO
Osage River near St. Thomas, MO	290111	926500	LM	MO
Osage River @ Warsaw, MO	290121	4*	LM	KS MO
Pomme De Terre River near Hermitage, MO	290131	921350	LM	MO
Sac River near Stockton, MO	290141	919000	LM	MO
Marais Des Cygnes River near KS-MO stateline	290103	916600	LM	KS MO
Gasconade River @ Jerome, MO	290202	933500	LM	MO
Missouri River @ Boonville, MO	300112	909000	LM	KS MO
Missouri River @ Kansas City, MO	300122	893000	MM	IA KS MO
Missouri River @ Hermann, MO	300202	934500	LM	MO
Missouri River @ mouth	300203	934500	LM	MO

*denotes special gage station

NOTE: UM - Upper Missouri, YS - Yellowstone, WD - Western Dakota, ED - Eastern Dakota, PN - Platte Niobrara, MM - Middle Missouri, KR - Kansas, LM- Lower Missouri.

With the exception of the mouth of the Missouri River, the downstream control points of those areas were located at gaging stations or reservoir outflow points having flow records during part or all of the selected 35-year study period 1944 through 1978. At some locations, the natural water supply in the Missouri River basin has been changed by imports, exports or transbasin diversions. The distribution of flows has also been modified by storage in man-made lakes. Water rights and legally required instream water under court decree or compact also have an impact on water availability. Following is a brief summary of the methodology used to quantify these factors.

Historical monthly flows for the Hydrology Study were determined at 93 locations. The mean annual flow at the most downstream stream gage in each of the eight subbasins is listed in Table 2. These flows are unadjusted for depletions except for the cumulative areas downstream that have been affected by changes in upstream imports or exports during the study period.

Table 2
Mean Annual Unadjusted Historic Streamflow, 1944-1978

Subbasin	Mean Flow (cfs)
Upper Missouri	10,900
Yellowstone	12,900
*Western Dakotas	25,600
*Eastern Dakotas	30,100
**Platte-Niobrara	7,460
*Middle Missouri	52,300
Kansas	8,200
*Lower Missouri	79,000

*Flow in these subbasins includes the accumulated flow from all upstream subbasins.
**Flow includes both the Platte River and the Niobrara River.

Imports into the Missouri River basin are made from the St. Mary's River in Montana, the Colorado River basin in Wyoming and Colorado, and from the Eagle River, a tributary of the Colorado River, through the Homestake Tunnel to the Arkansas River and then pumped to the headwaters of the South Platte River in Colorado. The general location of these imports is shown on the subbasin maps. Graphs showing the amount of water imported each year during the study period are also included in the subbasin sections. The total amount of water imported into the Missouri River Basin in 1978 was in excess of 500,000 acre-feet.

Exports of surface water from the Missouri River basin are made at two locations. The first is in Montana, where water taken from the Big Hole River is diverted to Butte, Montana. The second is near Springfield, Missouri, where water is taken from the Little Sac River. Both exports are for municipal water supplies. Total exports in 1978 were in excess of 30,000 acre-feet.

A total of 13 node basin transfers were considered significant in terms of the impact each has on the local surface water supplies. Transfers are made for hydropower, irrigation water supply, and flood control. Graphs showing the annual amount of water diverted at each location during the study period are located in the subbasin sections of this report. These transfers do not cross subbasin boundaries; therefore, they do not affect total water supply availability in each of the eight subbasins.

Regulation of surface water supply by storage reservoirs occurs at numerous locations throughout the Missouri River basin. For this study, significant regulation was assumed to occur when the normal capacity of a storage reservoir was 200,000 acre-feet or more. At the end of 1978, there were 28 reservoirs in the Missouri River Basin in that category. Reservoir operation programs were developed to regulate releases for 24 of those reservoirs. Rathbun Dam in Iowa, Hebgen Dam in Montana, Big Bend Dam in South Dakota and Keyhole Dam in Wyoming were excluded because their operation had little impact on the overall water availability within the Missouri River Basin.

The greatest impact major reservoirs have on the water supply is a leveling effect of natural streamflow. However, they also deplete the water supply through net evaporation from the lake surface. In the Missouri River basin, average annual evaporation totals 2.6 million acre-feet per year for the 24 major reservoirs included in this study. Graphs showing the evaporation depletion for each reservoir on an average monthly basis are presented in later subbasin sections of this report.

The entitlement or rights to surface water in the Missouri River Basin vary from state to state due to differences in political philosophies and laws that control allocation. Water right data and application process information have been summarized into narratives for each node basin. That information is located in the Water Accounting System database and is available through that system. Brief discussions of each states' water rights process is presented in the subbasin sections of this report.

The identification of irrigated lands in the Missouri River Basin, the agricultural water use related to the irrigation of those lands and the streamflow depletions resulting from irrigation were major activities of the MRB Hydrology Study. Estimates of streamflow depletions as a result of application of conservation measures, farm ponds and accretions to streamflow resulting from forest management practices were also evaluated.

For this report, data collected during the study were grouped into the eight subbasins within the Missouri

Table 3
Historic Trends — Acres Under Irrigation
(Surface and Ground Water)
(in 1,000's of acres)

Subbasin	1944		1960		1978	
	Surface Water	Ground Water	Surface Water	Ground Water	Surface Water	Ground Water
Upper Missouri	1,266	---	1,548	---	1,495	---
Yellowstone	1,102	---	1,263	---	1,149	---
Western Dakota	103	---	260	---	483	---
Eastern Dakota	---	---	24	13	262	126
Platte-Niobrara	1,730	238	1,985	809	1,963	2,914
Middle Missouri	---	---	53	4	282	16
Kansas	17	56	192	863	432	3,216
Lower Missouri	---	---	10	---	73	---
SUBTOTAL	4,218	294	5,335	1,689	6,139	6,272
TOTAL	**4,512**		**7,024**		**12,411**	

River Basin. Data was collected for the period 1944 through 1978. Irrigated acres by subbasin for selected year are shown in Table 3. Similar data is available from the Water Accounting System Database for each of the years 1944 through 1978 for each of the 93 node basins. From the database, the acres under irrigation, ground water versus surface water, show that surface irrigation acreage has remained relatively consistent over the period of study in all the subbasins. This is also true for ground water irrigation with the exception of the Platte-Niobrara and Kansas Subbasins. The approximate period of 1955 to 1978 shows a dramatic increase in the number of acres under ground water irrigation in those subbasins. Acres converted to ground water irrigation rose from about 900,000 to 6,000,000 during that time period. From 1944-1978, 7,899,000 additional acres were put under irrigation in the Missouri River basin. Of that total, 6,484,000 acres (82%) were in the Platte-Niobrara and Kansas Subbasins.

Streamflow depletions from irrigation of lands from surface and ground water are illustrated on Figure 2. In the Missouri River Basin, from 1944 to 1978, depletions for irrigation from ground water increased from 0.7% to 9.3% of the total depletion. Depletions due to evaporation from major reservoirs accounted for 15.1% of the total depletions in 1978. Depletions from all remaining categories were grouped into an "Other" category and are also displayed on Figure 2. Depletions for conservation measures and farm ponds increased during the 1944 to 1978 period. Acres of land treated by conservation measures increased during that period from 16.7 million to almost 56 million acres, while farm ponds increased by a total of over 420,000 acres for the same period.

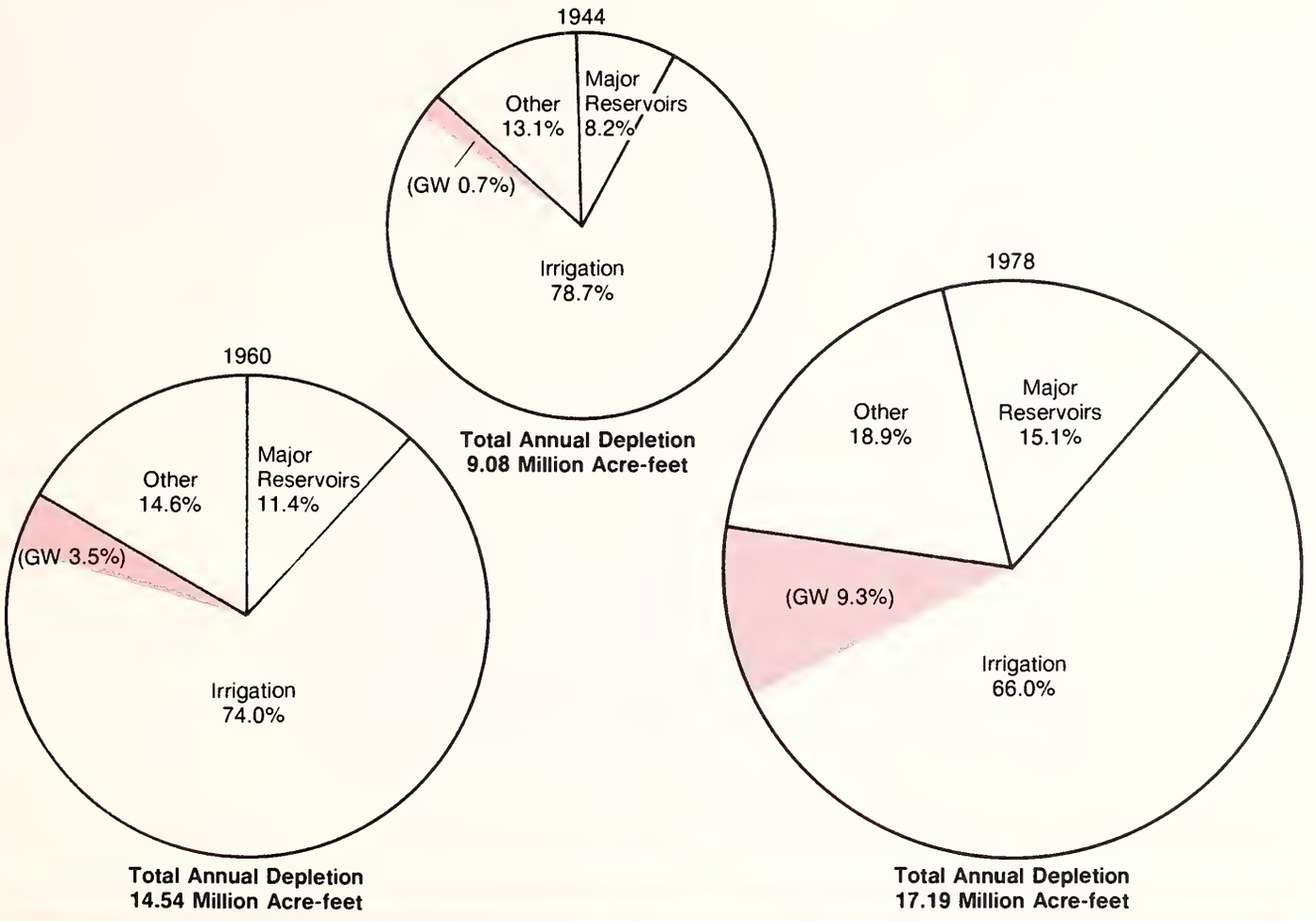
Data collection and analysis of water usage for purposes other than agriculture were conducted within four basic categories: municipal water use, self-supplied industrial water use, energy water use, and rural domestic water use.

Several significant facts and trends are evident in the data. Looking first from a subbasin viewpoint, the fastest growing total water use, by percentage, is found in the Eastern Dakota Subbasin; while the greatest increase in total water use, by volume, is found in the Platte-Niobrara Subbasin. Not unexpectedly, the Platte-Niobrara Subbasin is the largest user of water for municipal systems in 1978, primarily due to urban growth along the Front Range in Colorado (four of the ten largest cities in the basin are located in Colorado — Denver, Aurora, Lakewood, and Arvada). The only decrease in water use during the 1944-1978 period was for energy use in the Kansas Subbasin.

For the total Missouri River Basin, the fastest growing non-agricultural category of water use, by percentage, is for energy processing, extracting, and generation; while the greatest increase in water use, by volume, is for municipal systems. The largest non-agricultural uses of ground water, basinwide, are for municipal and rural domestic purposes.

Data for these four non-agricultural uses isolate several salient facts. Trends in average site use of water for energy and industrial purposes have varied widely over the eight subbasins. This is probably due to the variety of facilities involved; fluctuating economic conditions across the basin, particularly in the energy field; and in some instances, the relatively small database. The Middle Missouri Subbasin had the highest average per-site usage of energy water in 1978, and

Figure 2
Missouri River Basin
Total Annual Historic Streamflow Depletion
by Type of Use
1944, 1960 and 1978



	Other Depletions — Percent of Total		
	1944	1960	1978
Small reservoirs	3.1	2.6	3.8
Municipal, Industrial, Energy (Ground water pumpage)	0.5	0.6	0.8
Conservation Measures	1.4	2.6	3.2
Farm Ponds	1.9	3.4	4.1
Livestock	1.6	1.0	0.9
Municipal	2.1	2.1	2.9
Industrial	0.4	0.2	0.2
Energy	0.5	0.8	1.6
Rural Domestic	1.6	1.3	1.4
TOTAL	**13.1**	**14.6**	**18.9**

the Platte-Niobrara Subbasin had the highest average per-site use of industrial water in that year. With regard to municipal and rural domestic water, the data shows, that with minor exceptions, per-capita use in both categories has continually increased in all subbasins over the study period. The Middle Missouri Subbasin displayed the highest average per-capita use of water in both categories in 1978.

The total annual percent of historic streamflow depletions by subbasin are shown on Figure 3. In 1978 the Platte-Niobrara Subbasin accounted for almost one-third of the total depletions in the Missouri River Basin. That area, with its large increase in irrigated acres and municipal growth, is by far the area with the highest volume of water use in the Missouri River Basin. Together, the Upper Missouri and Yellowstone Subbasins accounted for about an additional one-third of the total streamflow depletions in 1978. As shown on Figure 3, the volume of depletions within the Yellowstone and Upper Missouri Subbasins had little change from 1944 to 1978, increasing from 2.10 to 2.35 million acre-feet in the Yellowstone Subbasin and from 2.40 to 2.98 million acre-feet in the Upper Missouri Subbasin. Other subbasins have had significant increases during that time period. The other five subbasins, Western Dakotas, Eastern Dakotas, Kansas, Middle and Lower Missouri, accounted for the remaining one-third of total streamflow depletions in 1978. Total streamflow depletions increased by 5.46 million acre-feet during the 1944 to 1960 period and

Figure 3
Missouri River Basin
Total Annual Historic Streamflow Depletion
by Subbasin

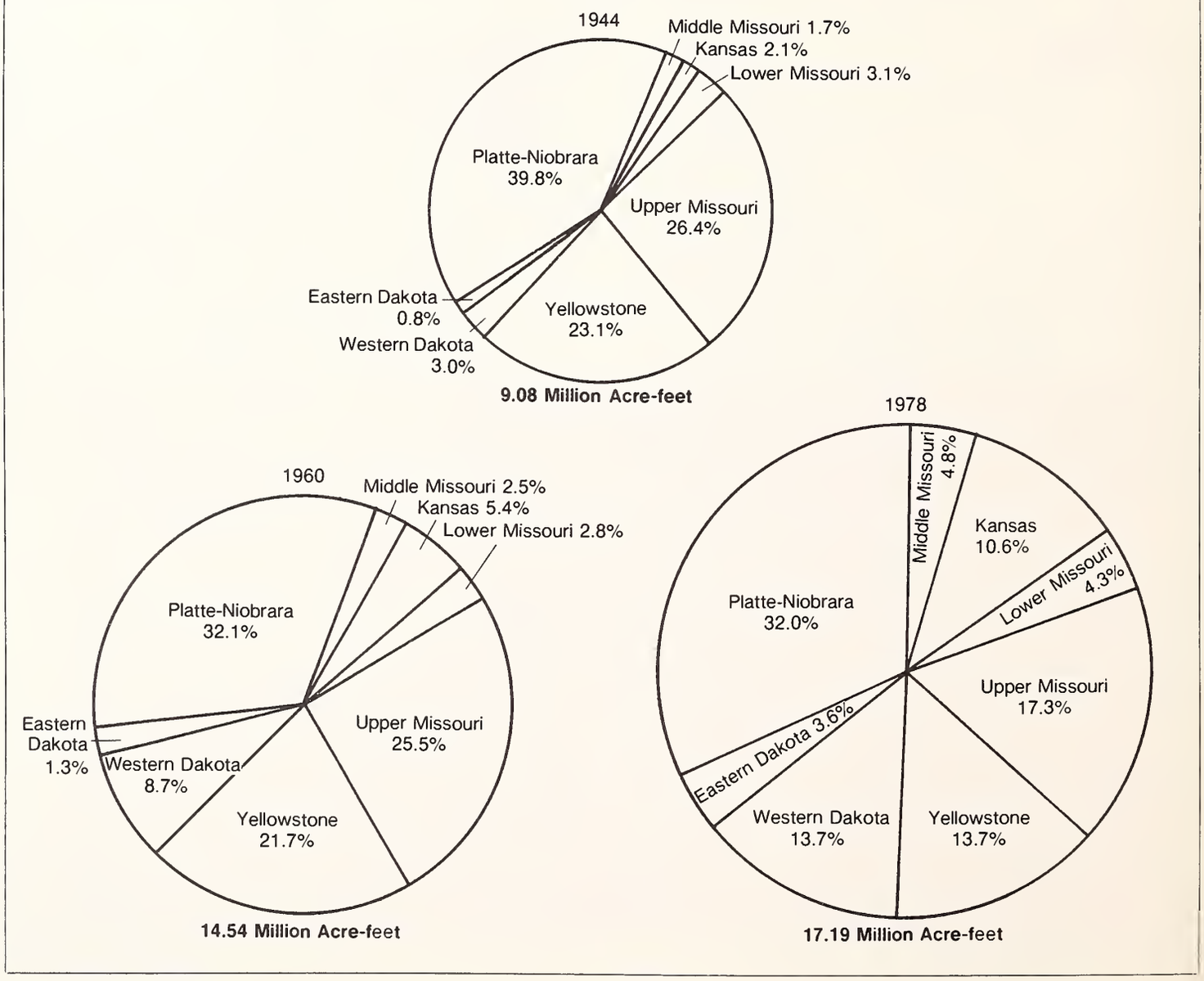
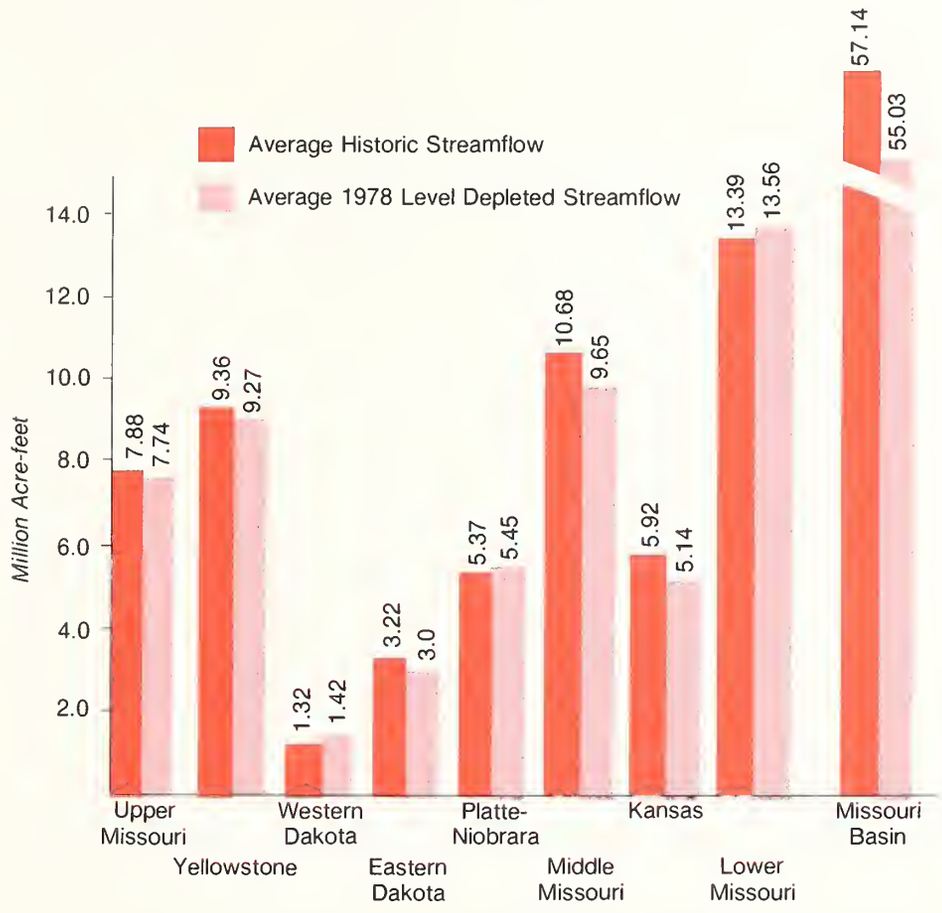


Figure 4
Comparison of Average Historic Streamflow and Average 1978 Level Depleted Streamflow, 1944-1978 by Subbasin and the Missouri River Basin



by an additional 2.65 million acre-feet from 1960 to 1978 (Figure 3). A comparison of the average historic streamflow and the average 1978 level depleted streamflow for the period 1944 - 1978 by subbasin and for the Missouri River basin is shown in Figure 4. The 1978 level depleted streamflow is estimated to be 21.43 million acre-feet at Sioux City and 55.03 million acre-feet at Hermann.

In the Missouri River basin, water supply studies have been made that extend back as far as the 1890's. After review of both water supply and available records for agricultural data, it was decided that a good starting point would be somewhere during the 1930's or 1940's. However, the bias that would be introduced into the study results by including both the 1930's drought and the 1950's drought was considered to have too great an impact to provide impartial results. Therefore, a period starting sometime after the 1930's drought was considered appropriate, and January 1944 was selected. However, in consideration of the significant negative impact a drought of that nature can have on a water supply situation and in anticipation of any question concerning its effect had it been included in the study, a "drought factor" relationship was developed for historical streamflow at selected gaging stations. Development of this factor was based on determining mean flows using the 1944-1978 and the 1930-1978 periods of records. For the Missouri River at Hermann, Missouri, that factor is 0.93, indicating the recorded mean annual flow during the 1930-1978 period was 93% of the mean annual flow for the period 1944-1978.

The Missouri Basin States Association maintains and operates the computerized Water Accounting System developed as a part of the MRB Hydrology Study. Users of the system can obtain information of estimated streamflow depletions due to any number of water uses within the 93 defined hydrologic areas, called node basins, that comprise the Missouri River Basin. Information on historic depletions is supplemented by narrative information about compacts, court decrees, and the general water rights processes and permit laws in effect in each of the ten Missouri River Basin states.

A computer program, entitled QUERY, is available for use to help determine the effects on streamflow of substantial changes in water demand of any kind in any of the node basins, groups of node basins or in the entire Missouri River Basin.

The extensive water use database and the computer programs that make up the MRB Water Accounting System provide the states and federal agencies that have a responsibility for water management in the Missouri River Basin, a tool that is unique in the United States. That tool, properly maintained and used, can do much for wise management of the basin's water resources by providing information on water use and availability within the Missouri River Basin.

GLOSSARY OF TERMS

Numerous technical terms or terms unique to this study are used in this report. Some have a variety of meanings or interpretations, even among water resource experts. The following definitions will be used consistently throughout this report.

accounting unit — an area that is drained by a river system, a reach of a river and its tributaries in that reach, a closed basin, or a group of streams forming a coastal drainage, as defined by the U.S. Water Resources Council.

aquifer — a formation, group of formations, or a part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

batch processing — a method of processing a quantity of data in one operation.

cathode ray tube (CRT) — a vacuum tube (television screen) sometimes used to display output from a computer system.

CIR adjustment factor — an adjustment in the crop irrigation requirement made for drier than normal years, since surface water is generally limited in dry years. The adjustment factor was used to reduce estimated irrigation depletions.

clear cut — a type of timber harvest in which all trees within the timber sale boundary are cut.

computer — an electronic machine for performing calculations.

computer program — instructions written in such a manner that they can be interpreted by a computer.

computer system — computer equipment (hardware) and computer programs (software) that are used together for input, processing, storage, and output of information.

consumptive water use — a use of water in which the return flow available following use is less than the amount of water supplied for use. Water is lost to the system through evaporation, transpiration, or metabolic processes.

contour farming — farming sloping land in such a way that plowing, preparing land, planting, and cultivating are done along the contour, not across it.

conveyance efficiency — the volume of water delivered to the farm, expressed as a ratio or percentage of the volume of water diverted from a stream or other water supply. Conveyance losses may include evaporation, seepage, or leakage.

crop distribution pattern — the proportional pattern, by area, of the irrigated crops which comprise the total amount of irrigated land in a node basin. A constant crop distribution pattern, based on 1978 conditions, was used throughout the entire study period.

crop irrigation requirement — the additional amount of water, supplied by irrigation, needed to supplement the effective precipitation to adequately grow a given crop to maturity.

data — factual material.

database — a collection of data stored as files that can be retrieved by a computer system.

debug — to locate and correct errors in software.

depletion — a loss of water from a surface water system as a result of man's activities. Such activities include, but are not limited to: evaporation from man-made reservoirs, transpiration from irrigated crops, metabolism from people and domestic animals, industrial processes, and discharge to an aquifer resulting from ground water use.

depletion study — a method of hydrological analysis which estimates depletions and depleted streamflows throughout a specified period. Likely effects of future projects or development can be assessed against past history of climatic, streamflow and development conditions.

depletors — a number of persons, animals, irrigated acres, industrial processes, or man-induced activities that causes a depletion, given in numbers per year.

diversion requirement — that quantity of surface water to be diverted from a stream to satisfy the crop irrigation requirement and conveyance losses for all full service, partial service, or waterspreader irrigation in a node basin.

effective precipitation — that portion of the total precipitation which is available to a plant for use in its physiological processes; losses occur due to evaporation, surface runoff, and deep percolation beyond the root zone.

equivalent clear-cut area — a data transformation parameter used in assessing the hydrologic effects of partial cuts and road building. Hydrologic effects were estimated for clear-cut areas with the effects of partial cut and road building then being assessed in comparison to that of clear-cuts. It was assumed that one acre of partial cut was equivalent to 0.4 acres of clear-cut, and that one mile of road construction was the equivalent of six clear-cut acres.

evapotranspiration — the process of converting water on the earth's surface to atmospheric water vapor, by either evaporation or transpiration.

farm ponds — small impoundments or dugouts of less than 40 acres surface area used primarily for livestock water.

forest accretions — the increased water yield from a forested watershed resulting from forest management practices. Practices such as harvest, thinning, or road construction remove vegetation, thus reducing ground cover and lessening the consumptive water use by plants. As a result, surface runoff is increased and an accretion to streamflow occurs.
forest type — a classification term relating to the dominant species of tree or trees in a forest stand as determined by species composition or crown class.
full service irrigation — that irrigation in which the entire crop irrigation requirement is available to provide full crop production in at least 8 out of 10 years.
graphic — representation by lines, bars or other geometric shapes.
ground water — water beneath the land surface that is contained in the zone of saturation. In a few localities, the top of a saturated zone may coincide with the land surface; but in most cases, water-saturated formations may be reached only by digging or drilling.
ground water irrigation — irrigation utilizing water pumped from subsurface aquifers.
hard copy — paper copy or similar medium that provides a document of computer output.
hardware — computer equipment, such as the CRT, printer, plotter, mainframe or other physical items.
historic depletion — the depletions which have occurred in the Missouri basin in the period 1944-1978, given in acre-feet, by month.
1978 level depletion — that part of the net depletion calculated by multiplying the historic unit rate of water used by the difference in depletors between 1978 and any years 1944-1977.
hydraulic conductivity or permeability of an aquifer — the volume of water that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow, expressed as gallons per day per square foot.
information — data that has been arranged into a meaningful and useful form.
input — the process of insertion of data into a data processing system. Opposite of output.
interactive program — a computer program that requires that the user input data during its execution.
irrigated land — land on which water is intentionally applied to a crop one or more times during the growing season for the purpose of enhanced agricultural production.
livestock daily water requirements — the gross amount of water needed per head per day for maintenance of physiological functions. In this study, requirements for five classes of livestock were given. While the requirements vary with regional climates and the season, constant rates were used basinwide in this study.
minimum (conservation) tillage — a form of non-inversion tillage that retains protective amounts of residue mulch on the surface throughout the year. Includes no tillage, strip tillage, stubble mulching, and other types of non-inversion tillage.
narrative — in terms of the MBSA database, a written summary of general information, compacts and court decrees, water rights, and state water laws.
net radiation — the difference between the downward and upward solar and long-wave radiation flux passing through a horizontal plane just above the ground surface.
net streamflow depletion — the sum of the historic depletions and the 1978 level depletions for a particular year.
node basin — a delineated hydrologic area that is drained by a river system; a subset of an accounting unit.
node basin number — a six-digit number used to identify the 93 node basins that make up the Missouri River basin drainage, created from the accounting unit number.
node basin outflow point — the locations throughout the Missouri basin at which depletions and depleted flows are summarized. Ninety-three such nodes were selected based upon four primary criteria:

a. U.S. Water Resources Council accounting unit outflow points;
b. State boundaries;
c. Mouth of a major stream; and
d. Major reservoir outflow point (conservation storage exceeding 200,000 acre-feet)

nonbeneficial consumptive use — consumptive use of water without any resulting direct economic benefit to man. An example is the use of water by riparian vegetation.
on-farm efficiency — the volume of water stored in the soil root zone and used by the crop, expressed as a ratio or percentage of the volume of water delivered to the farm. On-farm efficiency characterizes both the on-farm distribution system and the field application systems.
output — the process of receiving data or information out of a data processing system.
partial cut — a type of timber harvest in which only selected trees within the timber sale boundary are cut.
partial service irrigation — that type of irrigation in which the entire crop irrigation requirement is not available beyond a certain point in the growing season. A cutoff date of July 15th was used in the hydrology study for the upper basin states (MT, WY, ND, SD). In the lower basin states (NE, IA, KS, MO, MN, CO), one-half of the monthly crop irrigation requirement was provided for the irrigation season.
percent possible sunshine — the total time during which bright sunshine is received in a specified period (monthly for this study) expressed as a percentage of the total time during which bright sunshine is possible. The possible length of time varies with latitude at any given date and with the date at a given latitude.
range pitting — a mechanical grazing land treatment for the purpose of reducing surface runoff.
real-time — pertaining to the performance of data processing during the actual time the process is underway in order that results of the data being processed can be used in guiding the process.
record — a data set under a given file name.
regeneration — a term relating to the regrowth of for-

est vegetation following timber harvest or other disturbance.

remote sensing — collection of information or data about certain objects or conditions from a distance without physical contact. Examples are aerial photography and satellite-borne sensor systems.

reservoir inflow — a record of streamflow into any of the man-made reservoirs, given in acre-feet per month.

return flow — that portion of the water diverted for a beneficial use that returns to the stream system for potential rediversion or instream uses.

return flow distribution pattern — a temporal pattern which distributes the total return flow from a particular month's activity over the next 12 months on a monthly percentage basis. It recognizes that return flow is not instantaneous, but rather is logged over a period of time.

response curve — is a curve showing the relation between pumping time and volume of stream depletion.

rounding — the process of adjusting a numeric value according to some rule.

run — the execution of a computer program or routine.

software — computer programs and documentation.

specific yield of an aquifer — the change that occurs in the volume of water in storage per unit area of unconfined aquifer as the result of a unit change in head, expressed as a dimensionless ratio to the dewatered volume or the drainage porosity.

storage — pertaining to a device into which data can be entered, in which they can be held, and from which they can be retrieved at a later time.

stream depletion — either a direct depletion of the stream or reduction of ground water flow to the stream as a result of pumping a well in units of acre-feet.

stream depletion factor (SDF) — defined as $\frac{a^2S}{T}$, which has a dimension of time with "a" the distance from the well to the stream in feet, "S" the specific yield and "T" the transmissivity. The SDF has a unit of time and is the result of analyzing aquifer properties such as transmissivity, specific yield, and well location. When the well is pumped continuously and when the volume of stream depletion reaches 28 percent of the total volume pumped, the pumping time would be approximately equal to one sdf at the well.

subroutine — a part of a computer program.

surface water irrigation — irrigation utilizing water diverted by gravity systems, pumped from lakes or streams, or supplied from surface reservoirs.

terraces — an earth embankment, a channel, or a combination ridge and channel constructed across a slope.

test site — a specific location where classification techniques and ground truth information for a remote sensing study are evaluated and modified prior to implementation of a larger scale operational study.

transmissivity — the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to the hydraulic conductivity multiplied by the thickness of the zone of saturation. It is expressed as gallons per day per foot.

waterspreaders — a specialized form of surface water irrigation accomplished by diverting flood runoff from natural channels or watercourses and spreading the flow. The diversion and spreading is controlled by a system of dams, structures, dikes or ditches, or a combination thereof, designed to accommodate a calculated rate and volume of flow. Little or no manual control is needed.

Waterspreading differs from conventional irrigation in that the timing and volume of water applied are not made according to the needs of the crop. The timing and volume are dependent upon the nature of the surface water runoff and the infiltration capacity of the soil. A cutoff date of June 1 was assumed for this study in Colorado and Wyoming. In Montana, North Dakota, South Dakota and Nebraska, waterspreading was continued through June.

water table — refers to the common boundary between the saturated and unsaturated zones.

water yield — a term relating to the total surface and ground water runoff from a particular land parcel over a specified period of time. It is used in describing the hydrologic effects of forest management practices.

INTRODUCTION

Background and Authority

The Missouri River Basin Commission (MRBC) submitted a Proposal to Study to the U.S. Water Resources Council on June 28, 1978, entitled, "Missouri River Basin Hydrology Study." Federal funds for the study were received in time for a study start in 1980 under the authority of the Water Resources Planning Act of 1965 (P.L. 89-80, 42 U.S.C. 1962 as amended). The Plan of Study was adopted by action of the MRBC on February 5, 1980 and the study was initiated. Subsequently, the MRBC was terminated on September 30, 1981, by Executive Order 12319.

The ten states having formed the Missouri Basin States Association (MBSA), at its organizational meeting held September 28, 1981, adopted as its own the Missouri River Basin Hydrology Study, Plan of Study. By that action a commitment was made by the ten states in the Missouri River Basin to complete the Hydrology Study.

Study Budget, Area, Organization

The study was jointly funded by the Federal Government, through the U.S. Water Resources Council, and the ten states of the Missouri Basin States Association. The federal contribution totalled about $1.62 million. The state contribution was estimated at about $.58 million of in-kind services.

The Missouri River drains an area of 513,300[1] square miles in the United States and about 9,700 square miles in Canada. This area includes all of Nebraska, the majority of Montana, North Dakota, South Dakota and Wyoming, about half of Kansas and Missouri, and small parts of Colorado, Iowa and Minnesota.

The western boundary of the basin is made up of the Rocky Mountain Continental Divide. On the north, the basin boundary roughly follows the Canadian border. The east boundary is the Upper Mississippi River Basin and the south boundary the Arkansas-White-Red Basin. Beginning in Montana, the Missouri River flows generally in a southeastern direction a total of 2,315 miles to its confluence with the Mississippi River near St. Louis, Missouri. For this report the Missouri River Basin was divided into eight subbasins: the Upper Missouri, Yellowstone, Western Dakota tributaries, Eastern Dakota tributaries, Platte-Niobrara, Middle Missouri, Kansas and Lower Missouri, Figure 1 (page x).

In an area this large, the physiographic, climatic and other characteristics are bound to differ. The Rocky Mountain system of the west gives way to the glaciated and unglaciated Missouri Plateau in the north and central sections of the basin and to the high plains in the southwest. In the east, the central lowlands, the south central loess hills, and the central rolling plains of Kansas make up the rest of the Interior Plains. Two unique areas within the interior plains are the Black Hills of South Dakota and the Sandhills of Nebraska. The extreme southeastern tip of the basin consists of the Interior Highlands and Ozark Plateau. The climate varies widely across the basin, average annual total precipitation ranges from below 12 inches in the west to over 40 inches in the extreme southeastern part of the basin. Additional characteristics for the basin can be found in the individual subbasin sections of this report.

The study was conducted under the MBSA (previously under MRBC) with responsibility for the study delegated to the Study Director. The Study Director was assisted in the day-to-day conduct of the study by a team of MBSA staff coordinators who were assigned to work with each of five work groups. The work groups were chaired by MBSA or federal agency personnel and were composed of state and federal agency technical representatives. A management group with three federal and four state representatives assisted the Study Director in developing policy and operating guidelines. (Figure 5 illustrates the organization.)

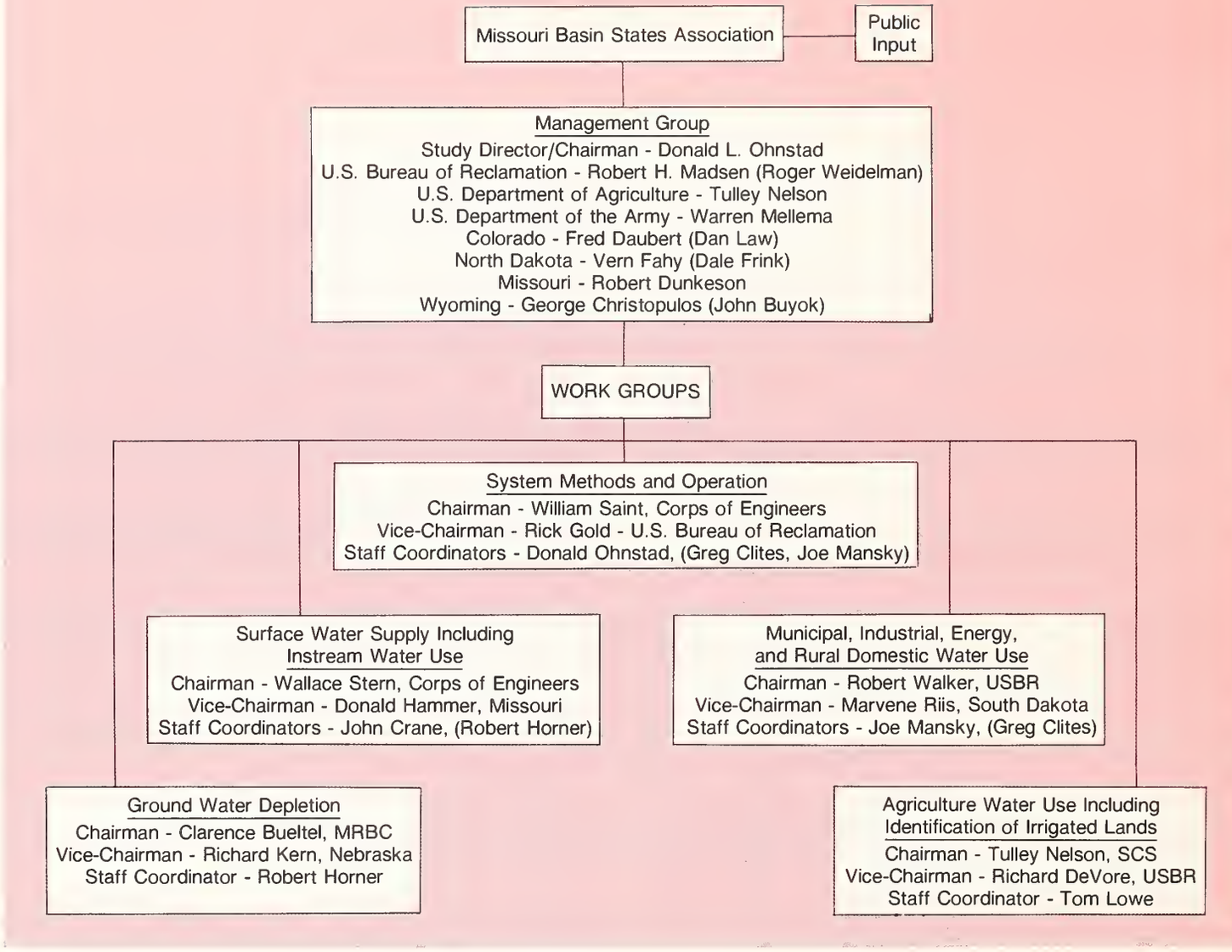
Under the Plan of Study each work group was assigned specific tasks associated with the study effort. Following completion of these activities each group prepared a technical paper which describes in detail their assigned activities.

General Study Methodology

The major objectives of the study were: (1) to develop an accurate and accepted base of information describing water availability and uses in the ten state Missouri River Basin; and (2) to develop a water accounting system for estimating the effects of using additional quantities of water in the future.

[1]Excludes 6,340 square miles in the Great Divide (Red Desert) Basin or other noncontributing drainage areas.

Figure 5
Study Organization


Missouri Basin States Association
Public Input
Management Group
Study Director/Chairman - Donald L. Ohnstad
U.S. Bureau of Reclamation - Robert H. Madsen (Roger Weidelman)
U.S. Department of Agriculture - Tulley Nelson
U.S. Department of the Army - Warren Mellema
Colorado - Fred Daubert (Dan Law)
North Dakota - Vern Fahy (Dale Frink)
Missouri - Robert Dunkeson
Wyoming - George Christopulos (John Buyok)
WORK GROUPS
System Methods and Operation
Chairman - William Saint, Corps of Engineers
Vice-Chairman - Rick Gold - U.S. Bureau of Reclamation
Staff Coordinators - Donald Ohnstad, (Greg Clites, Joe Mansky)
Surface Water Supply Including Instream Water Use
Chairman - Wallace Stern, Corps of Engineers
Vice-Chairman - Donald Hammer, Missouri
Staff Coordinators - John Crane, (Robert Horner)
Municipal, Industrial, Energy, and Rural Domestic Water Use
Chairman - Robert Walker, USBR
Vice-Chairman - Marvene Riis, South Dakota
Staff Coordinators - Joe Mansky, (Greg Clites)
Ground Water Depletion
Chairman - Clarence Bueltel, MRBC
Vice-Chairman - Richard Kern, Nebraska
Staff Coordinator - Robert Horner
Agriculture Water Use Including Identification of Irrigated Lands
Chairman - Tulley Nelson, SCS
Vice-Chairman - Richard DeVore, USBR
Staff Coordinator - Tom Lowe

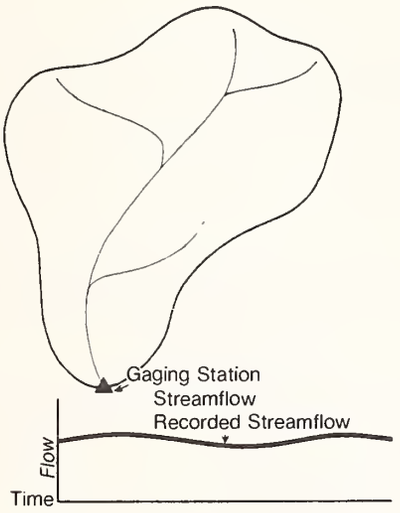
In final form the Missouri Basin drainage area was delineated into 93 hydrological drainage areas which were called node basins (see map in back pocket). In general, each stream outflow point for a node was located at a USGS streamflow gage that had a historic record period extending from 1944 through 1978. Besides the period of record other factors in selection of the node outflow points were: (a) location with respect to the Water Resources Council's hydrologic accounting unit outflow points; (b) proximity to state boundaries; (c) confluence of major streams; (d) below major reservoirs (greater than 200,000 acre-feet of conservation storage); and (e) general suitability for purposes of the study. All data for the study was then compiled based on those drainage area boundaries.

The MRB Hydrology Study was based on a depletion approach to describe the present water supply availability situation at the 93 node basin outflow points. The value of this approach is that it can be used to measure the likely effects of additional development under a variety of precipitation and water use conditions. Figures 6 through 9 illustrate the principles of the depletion study concept.

The general study methodologies used by the work groups are covered in the following sections. More detailed descriptions can be found in the Plan of Study and the technical papers prepared by each work group.

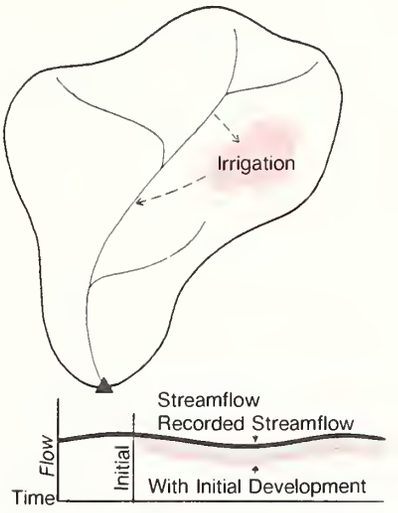
Surface Water Supply — Activities were related to defining historic surface water supply in the Missouri River basin for the period 1944 through 1978. These activities included selection of gaging stations, delineation of node basin boundaries, development of monthly historical streamflows, and identification of water imports and exports. Other activities included the estimation of surface water depletions due to evaporation from man-made lakes and compiling information concerning compacts, court decrees, and existing surface and ground water rights.

Figure 6
Pre-development



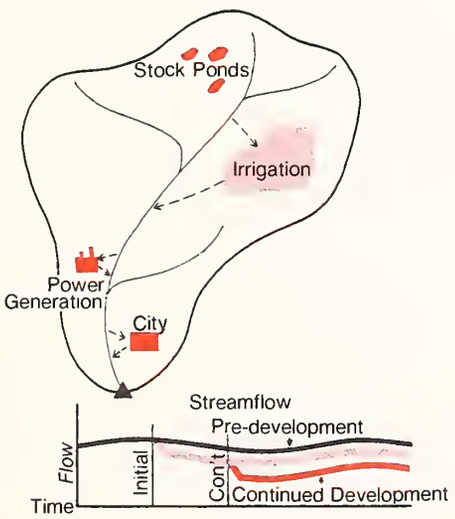
This diagram is depicting a node basin before any development, three tributaries contribute to the main stream. The normal streamflow at the gaging station could be expected to fluctuate over time due to varying precipitation as shown in the graph.

Figure 7
Initial Development



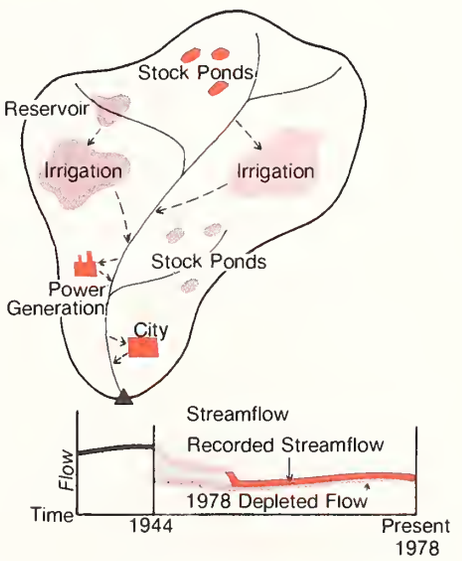
At some point in time, development begins. In this case, for example, an irrigation project is the initial development in the node basin. Water use begins to have an effect on streamflow, as shown in the graph. The shaded area on the graph indicates the losses (depletions) to streamflow due to the irrigation.

Figure 8
Continued Development



As development continues to occur in the node basin, streamflow records would reflect that development. The difference between pre-development and the effects of man-induced water use is depicted on the graph.

Figure 9
Today's Development



A depletion study adjusts recorded streamflows for the period of study to reflect the level of development present today (1978). The graph shows 1978 development conditions imposed on earlier times. The shaded area shows how much less water would have been present as streamflow if 1978 level development had been in place in earlier times. It is important to note that the 1978 depleted streamflow line could be above the recorded streamflow line. Reasons for that condition could include lower levels of development in 1978 then in past years, impacts of large reservoirs, imports of water, and perhaps other causes.

Considering the major impact that man-made reservoirs have on the normal flow sequences of affected streams, it was necessary to include some procedures in the Water Accounting System that accounted for reservoir effects due to redistribution of flows from reservoir operation. Since there are literally thousands of man-made lakes in the Missouri River basin, it was necessary to limit the number of reservoirs studied in detail within the Water Accounting System. In the final selection process, reservoirs with a normal capacity of 200,000 acre-feet or greater were selected. Exceptions were Hebgen Dam in Montana, Rathbun Dam in Iowa, Keyhole Dam in Wyoming and Big Bend Dam in South Dakota. These four were, in the final analysis, excluded from the major reservoir group because their depletion effects were minimal or because of unique operational considerations. Two types of reservoir operational programs were used for major reservoirs: the Corps of Engineers Missouri River main stem reservoir computer program for the six Corps of Engineers reservoirs on the Missouri River, and a generalized reservoir operating program written by the Bureau of Reclamation for the other 19 major reservoirs. Some river systems within the Missouri River basin are controlled by international treaty, interstate compact, or court decree. While significant, they represent less than half of the total region (Figure 10). For the large remaining area, in particular with respect to the Missouri River itself, there is growing interest in and concern about what the future may bring.

Ground Water Use — The purpose of the ground water studies was to quantify depletions to streamflow caused by ground water pumpage. Because quantifying ground water depletions to streamflow for all streams throughout the Missouri River basin would have been beyond the scope of study and because total streamflow depletions due to ground water pumpage in many parts of the basin are insignificant, detailed depletion analysis was limited to two subbasins of significant ground water use. These were the Platte River Subbasin and the Kansas River Subbasin.

The most significant distinction of the ground water depletion is the time delay effect on streamflow and the cumulative effect of previous pumping. The technique selected for analyzing streamflow depletions due to ground water pumpage was the Stream Depletion Factor (SDF) technique. The Stream Depletion Factor method was chosen because of its use of a partial transmissivity grid of the aquifer with interpolation between grids, its ability to analyze groups of wells instead of analyzing each well separately, and the comparability of its results to other more detailed methods.

The SDF technique is applied on a stream-aquifer system where the stream and aquifer are hydraulically connected. The technique is used to determine the effect on streamflow of pumping water from the aquifer. The technique numerically solves the unsteady ground water equation to derive a factor called the stream depletion factor (sdf) which characterizes the aquifer properties of and the distance from the stream to the location of a well. The stream depletion factors obtained at various locations in the stream-aquifer system are registered onto a map and divided into several bands of different sdf ranges. The average value of the sdf band, schedule of pumping and amounts of water pumped are then entered into a computer program to determine the stream depletion. To illustrate the concepts, referring to Figure 11, water pumped from the wells is derived partly from the stream, as indicated by the steepened water table near the stream and partly from the aquifer, as indicated by the lowered water table near the well.

The transmissivity of an aquifer is a measure of the capability of the aquifer to transmit water horizontally under specified conditions. A map of the distribution of lines of equal transmissivity (Figure 12) is required to calculate the effects of pumping wells on the flow system. Transmissivity is normally determined by aquifer testing using records of pumped wells. Zones of equal transmissivity, T, are illustrated in Figure 12. However, a more accurate map of transmissivity showing actual isograms is required for calculations. If the surrounding material does not transmit water readily, its transmissivity may be regarded as zero, which indicates that water does not flow horizontally.

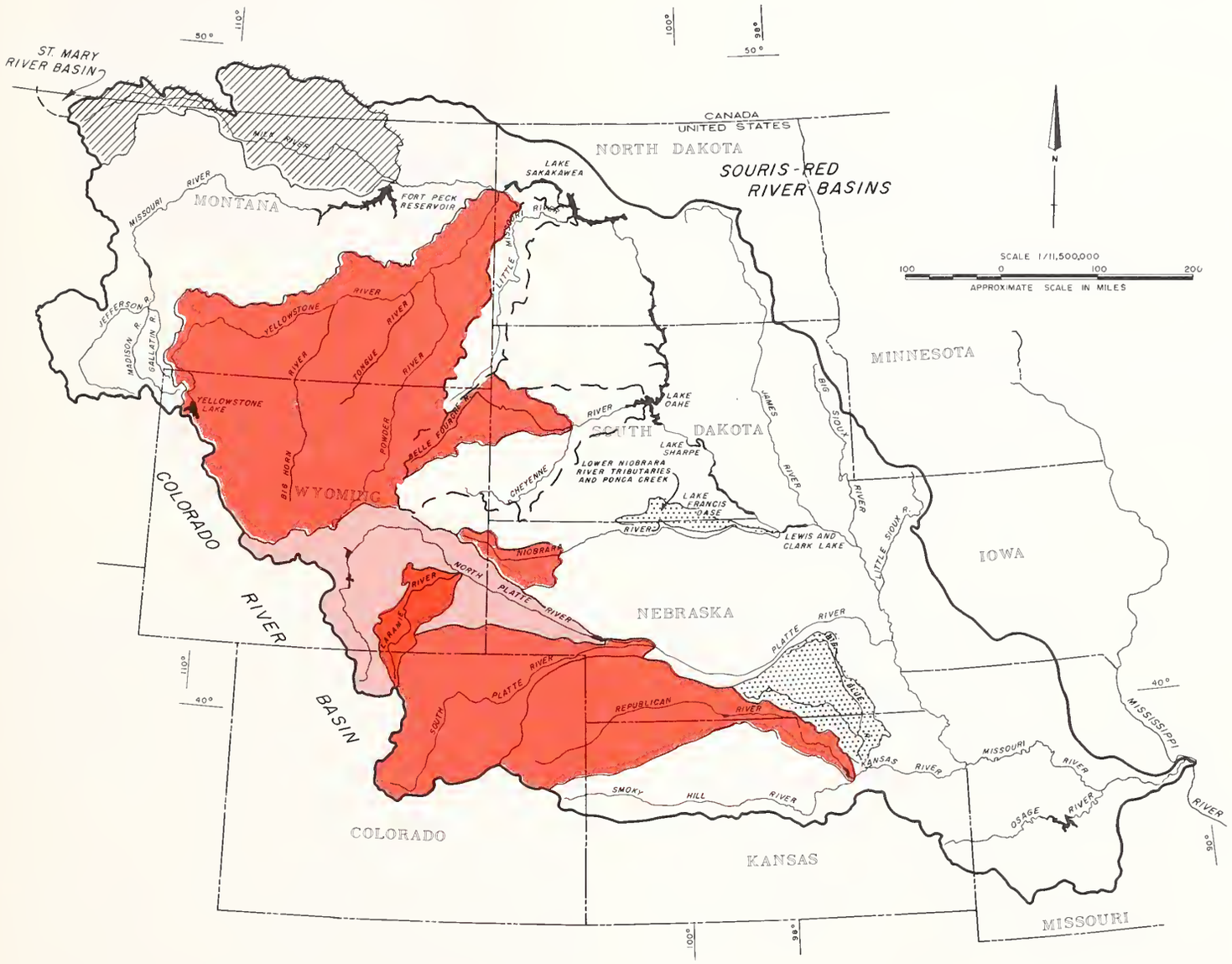
Using the SDF technique, an imaginary grid network is drawn over a transmissivity map, Figure 13. By assigning local values of transmissivity to each element of the grid, the distribution of transmissivity is approximated. Local values of the aquifer storage characteristics may also be assigned to each element of the grid. For this study, storage values were assumed to be uniform over the aquifer grid.

In order to observe the response of the stream to pumping, imaginery wells are simulated at various distances from the stream. Through the use of a SDF computer program, the imaginary wells are pumped separately, and the resulting effects on the stream are estimated and plotted.

Wells can obtain their pumped water either from the stream or aquifer or a combination of both. Wells located close to the stream tend to deplete the stream rapidly, whereas wells located some distance landward from the stream tend to deplete the stream at a much slower rate. Detailed explanations of the SDF technique and associated computer programs are included in the technical paper prepared by the Ground Water Work Group.

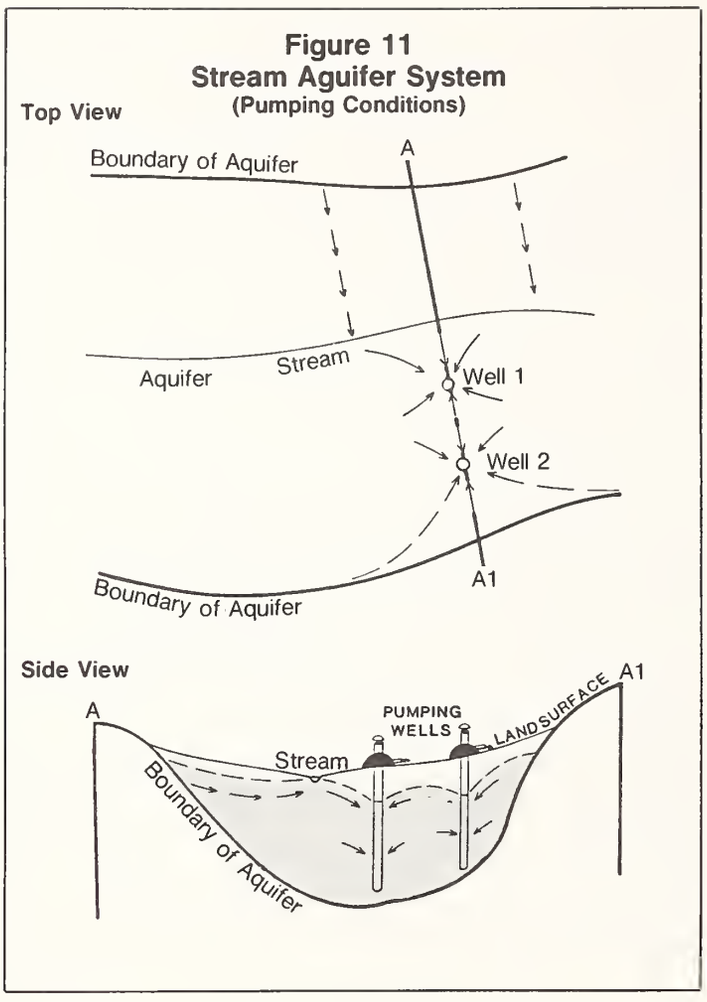
Agricultural Water Use — The primary tasks of this work group were identification of irrigated lands throughout the Missouri River basin and estimation of streamflow depletions resulting from irrigation of these lands. Other tasks included collection of information and estimation of streamflow depletions resulting from farm conservation practices, farm ponds,

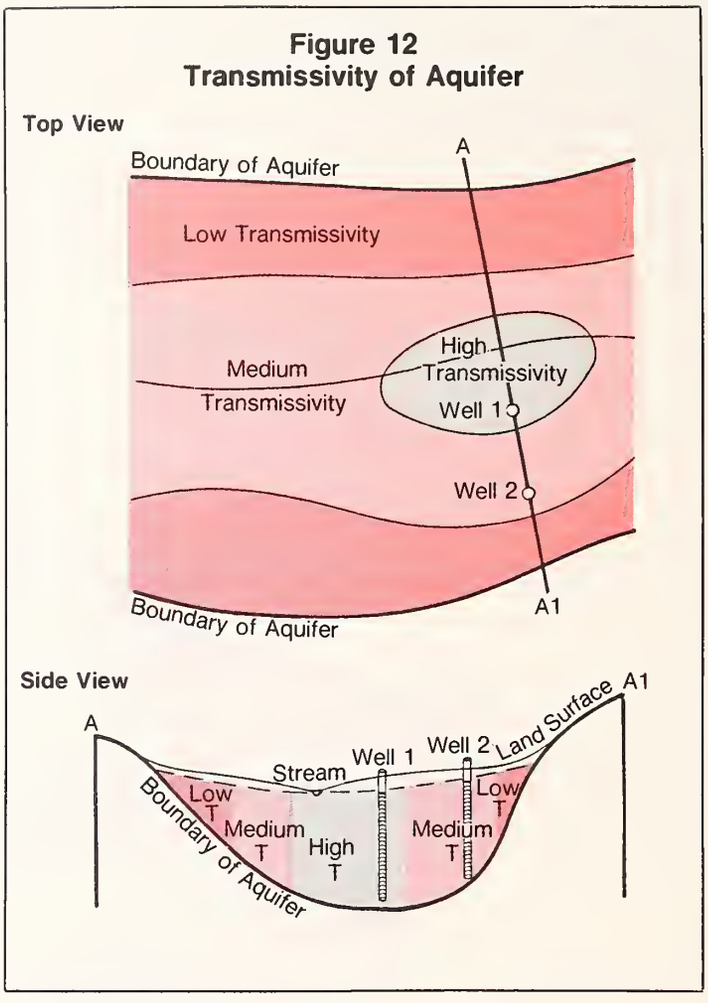
Figure 10
Missouri River Basin
International Waterways Treaty, Interstate Water Compacts, and Supreme Court Decrees



LEGEND

- INTERNATIONAL TREATY
- EXISTING INTERSTATE WATER COMPACT
- PENDING INTERSTATE WATER COMPACT
  - ACTIVE NEGOTIATION
  - INACTIVE NEGOTIATION
- UNITED STATES SUPREME COURT DECREE
- MISSOURI RIVER BASIN BOUNDARY





and livestock water consumption. Accretions to streamflow resulting from forest management practices also were estimated.

Information was compiled on each "depletor" (number of acres irrigated, number of head of livestock, etc.) for all depletion categories in each of the 93 node basins for inclusion in the Water Accounting System database. Corresponding depletion estimates for each individual category were then made and included and stored in the database. Information collected by this work group was utilized in the Ground Water Depletion study for the 22 node basins in the Platte and Kansas River Subbasins.

In general, node basin "depletors" were determined for each depletion category from which streamflow depletions were estimated using established or estimated diversion requirements, efficiencies, return flow requirements, or other appropriate factors. The starting unit for data collection was usually at the county-level, from which portions of node basins within each county were aggregated into node basin totals.

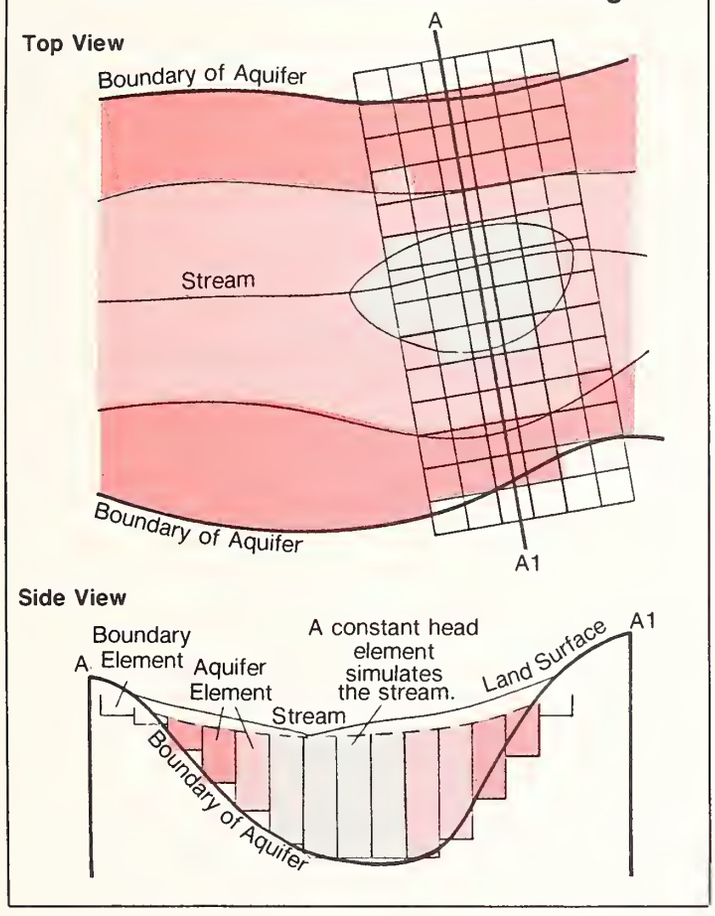
Several sources of data were used to compile irrigation acreage and other information. An extensive review and concurrence procedure was established to ensure that the state and federal agencies would have the opportunity to review and concur in all the estimated depletors and their resulting depletions.

Irrigated acreage data, by county, and by year, were available for the period 1944 through 1974 at five-year intervals from the U.S. Census of Agriculture. Acreages for the noncensus years were estimated using straight-line interpolation between the preceding and succeeding census values. Acreages for 1978 were estimated through the cooperation of the states and several federal agencies using sources listed in the work group's technical paper.

Information in addition to county-level irrigated acreages was necessary for the computation of streamflow depletions due to irrigation. This included crop type, type of irrigation system used, source of water, intensity of use and efficiency of use. Since this type of information is not usually available in published reports or agency data, another source was sought. Field personnel of the Soil Conservation Service were asked to assemble the information, which was provided by SCS District conservationists throughout the Missouri River basin.

A fundamental question requiring resolution was whether to use a single or multiple crop distribution pattern in calculating the crop irrigation requirement. Use of the single pattern would involve imposing a constant pattern for a selected year on each year of the 1944-1978 study period. The multiple pattern would involve determining the cropping pattern for selected key years and interpolating to estimate pat-

Figure 13
Grid for Use in Mathematical Modeling



terns for intervening years. A concern was the fact that certain crops, due to the length of their growing season and water consumption rates, would affect overall water use more significantly than others. Tests were made to determine the significance of using a single or multiple cropping pattern. As a result of those tests, it was determined that multiple cropping patterns had an insignificant impact on the overall water requirements; therefore, a single cropping pattern for the year 1978 was used throughout the period of study.

The estimate of streamflow depletions due to irrigation is a complex procedure requiring information about many interrelated factors. Included among these are the acreage of irrigated crops, delivery and on-farm system efficiencies, and return flow distribution patterns. Of vital importance in this estimation is the crop irrigation requirement (CIR).

In much of the Missouri River basin, precipitation during the growing season is usually inadequate to grow many crops to maturity. In other parts of the basin, precipitation may be adequate on the average but is often inadequate in any one year. Only along the eastern part of the basin is precipitation usually adequate for a wide range of crops. For the remainder of the basin, where normal precipitation is inadequate, alternative means of supplying satisfactory amounts of water is often needed. The crop irrigation requirement is the additional amount of water, supplied through irrigation, needed to supplement the effective precipitation to adequately grow a given crop to maturity. Accurate estimates of the CIR are necessary if realistic irrigation depletion estimates are to be made.

This study recognizes three intensities of irrigation water use: full service, partial service and waterspreaders. It should be realized that the crop irrigation requirement has little, if any, relationship to depletions from waterspreading due to the nature of this practice. Waterspreading depletions are primarily influenced by the availability of water for diversion and the amount of moisture present in the soils at the time of diversion. Accordingly, waterspreader depletion estimates were made differently.

Numerous methodologies are available for estimating crop consumptive water use or the crop irrigation requirement. Given the subhumid to semiarid nature of the Missouri River Basin, it was decided that the Blaney-Criddle and Jensen-Haise methods best represented the actual crop consumptive use in the basin.

The state work group members selected the consumptive use method (Jensen-Haise or Blaney-Criddle) which best represented conditions in their state or provided continuity with other investigations in their state. The following list summarizes those selected:

Colorado — modified Blaney-Criddle
Iowa — modified Blaney-Criddle
Kansas — modified Blaney-Criddle
Minnesota — modified Blaney-Criddle
Missouri — modified Blaney-Criddle
Montana — modified Blaney-Criddle
Nebraska -Jensen-Haise
North Dakota — Jensen-Haise
South Dakota — Jensen-Haise
Wyoming — modified Blaney-Criddle

All input data and depletion estimates from this study are ultimately on a node basin basis. Since many node basins cross state boundaries, the problem of which consumptive use method to use for interstate node basins arose when the states involved preferred different methods. This occurred in approximately one-third of the 93 node basins. Where this problem arose, the method preferred by the state having the greatest irrigated acreage in the node in 1978 prevailed.

Estimates of livestock water use and associated streamflow depletions were made on a monthly basis throughout the 1944-1978 study period. The livestock number estimates were compiled for each of five categories as follows: (1) milk cows, (2) all other cattle and calves, (3) all hogs and pigs, (4) all sheep and lambs, and (5) horses, ponies, and mules. Data on livestock numbers were available from the U.S. Census of Agriculture and the cooperative state Crop and Livestock Reporting Services. Estimates of livestock numbers in noncensus years were determined by assuming a constant (linear) rate of annual change between cen-

sus years from 1944-1974. Crop and Livestock Reporting Service livestock estimates were used for the years 1975-1978 if they were available. The county-level estimates of livestock numbers were aggregated to the various node basins. It was assumed for distribution between node basins that livestock would be uniformly distributed throughout each county.

Surface water depletions due to four separate land treatment practices, and farm ponds were estimated. These practices were: (1) contour farming, (2) terraces, (3) minimum tillage, and (4) range pitting. Depletions from farm ponds with fewer then 40 acres in surface area were also considered. As indicated earlier, data were collected at the county level and aggregated by node basin. It was assumed that land conservation practices and farm ponds were uniformly distributed throughout each county and distributed to node basins on that basis. Information available from the aggregate data includes total node drainage area, acreage total for each land conservation practice, and percentage area affected by county by node for all nodes in the basin. A time distribution curve was developed for the base years 1944, 1950, 1960, 1970, and 1978. This distribution was used for determining acreages and depletions for all years. Estimates for intervening years were determined by assuming a constant rate of change between base years. Yearly depletion estimates were made for average weather conditions and distributed on a monthly basis. A single monthly depletion distribution was used for the entire basin.

Approximately 27 million acres or eight percent of the Missouri River basin is forested. Approximately 16 million acres are located in the Rocky Mountains with the remainder primarily located in the Black Hills, Ozark Highlands, and along streams. These forests, particularly in the Rocky Mountains, are more important from a hydrological standpoint than their relatively limited extent would imply. Mountain forests usually occur in areas which experience heavy accumulations of snow. Runoff from many such forests exceeds one acre-feet per acre per year compared to less than one inch of runoff occurring annually over most of the Great Plains portion of the basin. Forest management practices affect water yields in two principle ways: through snow distribution and on-site evapotranspiration changes. These influences are such that they can increase water yield from forested watersheds to a level in excess of that from virgin-forest conditions.

Forest Service regions covering Montana, Wyoming, and Colorado provided information on water yield resulting from forest management practices in those areas. In the remaining basin states, the water yield increased from forest management is relatively minor and short-lived; therefore, the effects on streamflow would probably not be measurable. Twenty-two node basins were selected for detailed analysis of forest water yield accretions. The historical data used were collected by administrative unit for the National Forest and by county for state and private lands. These data were allocated to node basins using a proportional area method. Details on the methods used to develop these effects are shown in the work group technical paper.

Municipal, Industrial, Energy, and Rural Domestic Water Use — Data collection and analysis of water usage for purposes other than agriculture were conducted within four basic categories: municipal water use for cities with populations above 2,500, self-supplied industrial water use, energy water use, and rural domestic water use.

Data were collected for the 93 selected drainage areas for five record years: 1944, 1950, 1960, 1970 and 1978. The first step in disaggregating this data was to breakdown the data into an annual record of water use. This was done by dividing the difference between subsequent record year water use into the number of years between record years. The second step in the process was to further breakdown the annual consumptive use figures into monthly figures. This was done by dividing the annual total consumptive use by a monthly distribution factor. Two distributions were developed, one for energy and industrial use and another for municipal and rural domestic water use.

For this study, for these four categories of water use, the data were collected and compiled by state personnel. While sources used varied from state to state municipal water use records and state permitting records were the major data sources.

WATER USE AND AVAILABILITY

As described in a previous section of this report, water use is accounted for by net depletions to streamflow. Water availability is accounted for by monthly adjustment of net depletions to historic streamflow. The following sections describe streamflow depletions and water availability on a subbasin basis.

Upper Missouri Subbasin

The Upper Missouri Subbasin covers 82,755 square miles in the extreme northwest part of the Missouri River Basin, Figure 14 (page 23). Here the principal tributaries of the Missouri, the Jefferson, Madison, and Gallatin Rivers meet at Three Forks, Montana to form the Missouri River. These rivers originate in mountainous areas and then flow through level to gently rolling plains. Elevations in the basin range from 1,860 to 11,293 feet. The topography is of two types: a series of intermountain valleys descending from the Rocky Mountains in the west, and a large table land prairie, broken by deeply entrenched, narrow, meandering streams in the northern and eastern parts of the subbasin.

The majority of the subbasin area is located in the State of Montana with small areas also in Wyoming and North Dakota. A small percent of the basin lies in the southern Canadian provinces of Alberta and Saskatchewan.

Grassland is the predominate ecosystem with areas of cropland dispersed throughout the subbasin. Ranching and farming, with production of livestock and small grains is the predominate economic activity in the subbasin. Mining, tourism, and forestry are also important sectors of the economy.

The ground water resource in this subbasin is limited to small alluvial aquifers near streams. While generally sufficient for domestic use, this supply does not provide for extensive irrigation development. Overall, ground water is not an important source of water in this subbasin.

The majority of the surface water in this subbasin originates as mountain snow in the Rocky Mountains. As a result, high flows occur in the spring and early summer months of May and June. The surface water outflow point selected for this subbasin is the USGS gage number 06185500 located on the Missouri River near Culbertson, Montana. The drainage area above that point is 91,557 square miles. For the 1944 to 1978 period of record, the average recorded streamflow at that point was about 10,872 c.f.s. or 7.88 million acre-feet annually.

Water imported or exported can have a substantial impact on water supply availability, particularly if the quantities involved constitute a significant part of the total flow at a given point. In this subbasin there is an import of water from the Saint Mary's River basin. In addition, one of only two exports of water from the Missouri River basin occurs in this subbasin. That export is for water supply to the City of Butte, Montana from the Big Hole River. Imports and exports of water generally are tied to a specific use, therefore, the quantities may vary from year to year depending on climatic or other conditions. Figure 15 shows the annual volume of water imported via the St. Mary Canal near Babb, Montana. As shown, imports over the 35 year time period have varied from a low of 80,000 acre-feet to a high of 220,000 acre-feet annually.

The annual amount of the Big Hole River export to the Butte water supply was constant at about 13,500 acre-feet per year (Figure 16).

In the Upper Missouri Subbasin, there are four major reservoirs, Figure 14. Fort Peck is the largest with a normal capacity of 15.4 million acre-feet. This reservoir is the oldest and the furtherest upstream of the six Missouri River main stem reservoirs operated by the Corps of Engineers. The Bureau of Reclamation constructed two major reservoirs in this subbasin, Canyon Ferry and Tiber with normal capacities of 1,947,000 and 967,300 acre-feet, respectively. Holter Dam with a normal reservoir capaciy of 245,000 acre-feet is the largest private reservoir development in this subbasin.

Evaporation of water from the surface of man-made reservoirs is a major depletor of water. As shown in Figure 17, the average monthly evaporation from the Tiber reservoir during the peak evaporation months of July and August is approximately 5,000 acre-feet. During July and August, for the Canyon Ferry reservoir, average monthly evaporation is approximately 15,000 acre-feet, Figure 18.

Because of the reservoir depth, peak evaporation at Fort Peck reservoir occurs at a somewhat later period of the year, Figure 19. In September, it is estimated that the average monthly net evaporation at Fort Peck reservoir exceeds 100,000 acre-feet. Net evaporations for the six main stem reservoirs were obtained from the Corps of Engineers reservoir operations. Net evaporation for main stem reservoirs, as shown in Figure 19 for example, takes into consideration the heat energy stored in the reservoir. Evaporation for the trib-

Figure 15
Annual Water Import
St. Mary Canal near Babb, Montana

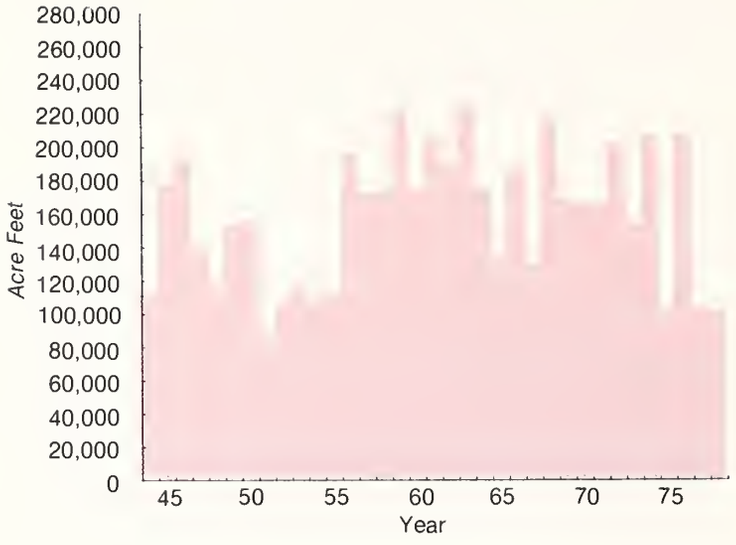


Figure 16
Annual Water Export
Big Hole River to Butte Water Supply

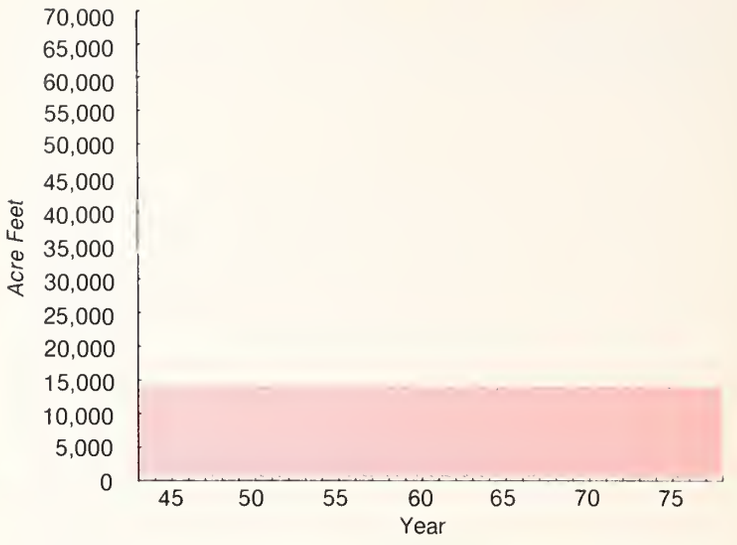


Figure 17
Average Monthly Evaporation
Tiber Reservoir

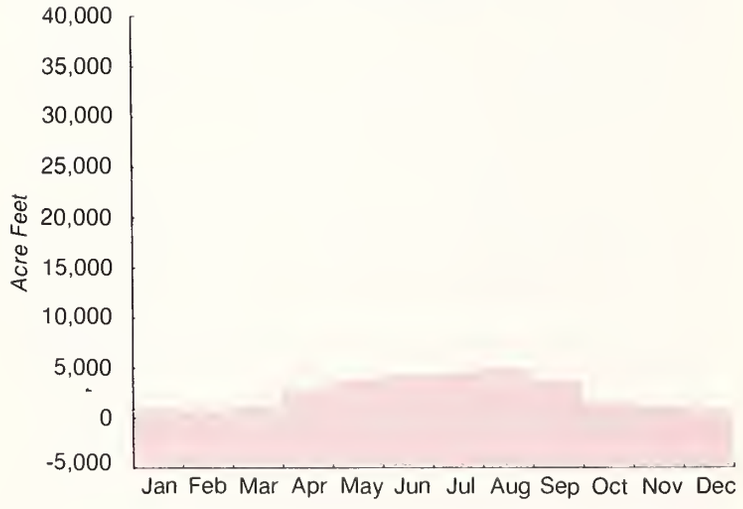


Figure 18
Average Monthly Evaporation
Canyon Ferry Reservoir

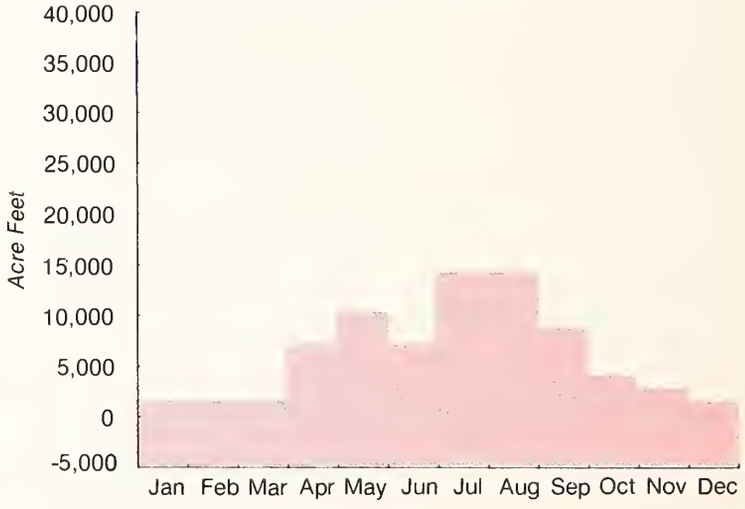
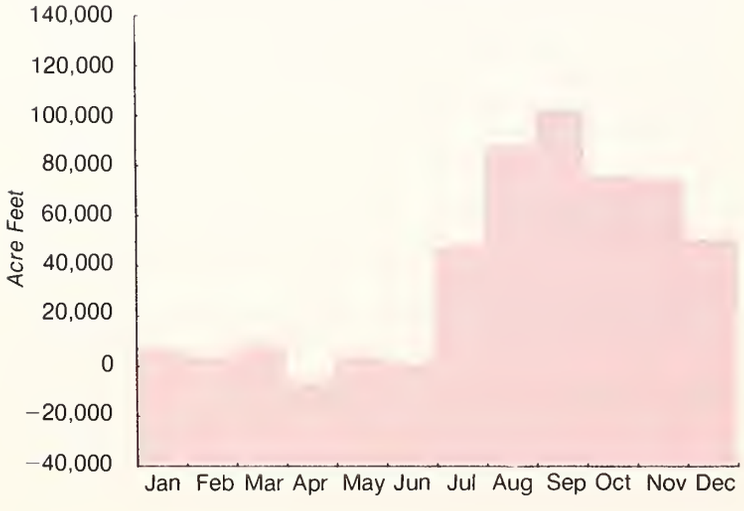


Figure 19
Average Monthly Net Evaporation
Fort Peck Reservoir



utary reservoirs, as shown in Figure 18 for Canyon Ferry Reservoir, was estimated from pan evaporation and therefore may be less accurate than that estimated for main stem reservoirs. In this subbasin, total depletions from evaporation from major man-made impoundments average about 584,100 acre-feet annually, while evaporation from all small reservoirs in the subbasin average about 110,200 acre-feet annually.

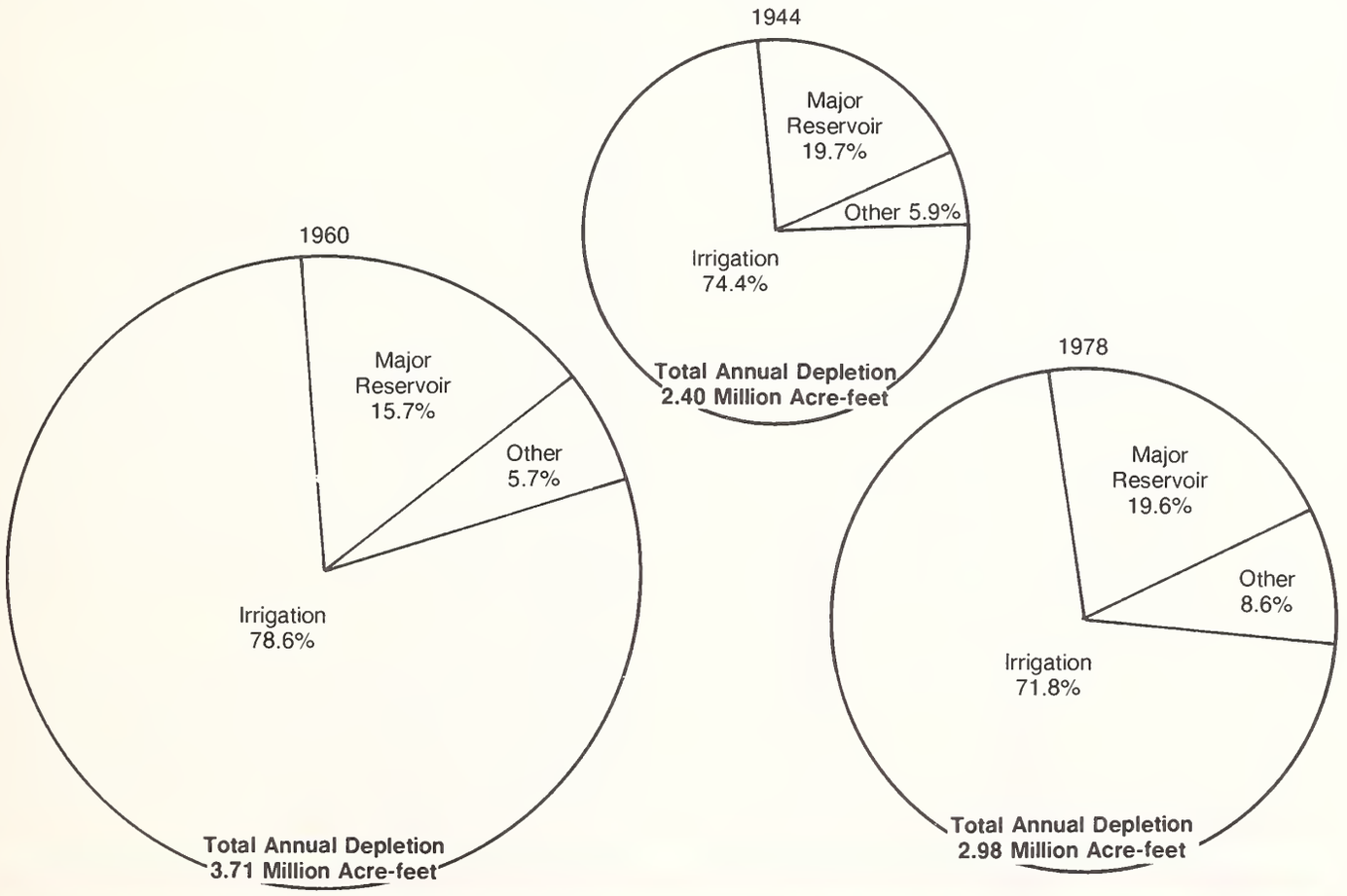
Waters in the State of Montana are considered public. In Montana, different statutory procedures exist for the appropriation of water by private parties than those for governmental entities. Since 1973 private party appropriations may be made only after a permit is obtained from the State Department of Natural Resources and Conservation. Under the 1973 Water Use Act, Montana recognized instream rights and allowed the maintenance of such water uses. However, on fully appropriated streams, there is no legal means to pur-

Figure 14
Upper Missouri Subbasin

chase, donate, or otherwise secure water rights for in-stream flow purposes even from willing sellers. Within the subbasin, the Boundary Water Treaty involves the St. Mary and Milk Rivers flowing between Montana and Canada. Under this treaty, during the irrigation season between the first of April and the thirty-first of October, inclusive, the United States is entitled to an appropriation no less than 500 cubic feet per second of the flow of the St. Mary River, or an amount which constitutes three-fourths of the river's natural flow. Canada is entitled to a like amount during the same time period from the Milk River.

As a part of the MRB Hydrology Study, several categories of water use were identified and estimates of water depletions were made. In the Upper Missouri River Subbasin, the major water user is irrigation. As shown in Figure 20, irrigation has accounted for over 70 percent of all depletions in this subbasin. Over the

Figure 20
Upper Missouri Subbasin
Total Annual Historic Streamflow Depletion
by Type of Use
1944, 1960 and 1978



Other Depletions — Percent of Total

	1944	1960	1978
Small Reservoirs	3.7	2.7	3.7
Conservation Measures	0.6	0.7	1.2
Farm Ponds	0.8	1.4	2.4
Livestock	0.3	0.2	0.3
Municipal	0.1	0.2	0.3
Industrial	0.1	0.1	0.1
Energy	—	0.1	0.1
Rural Domestic	0.3	0.3	0.5
TOTAL	**5.9**	**5.7**	**8.6**

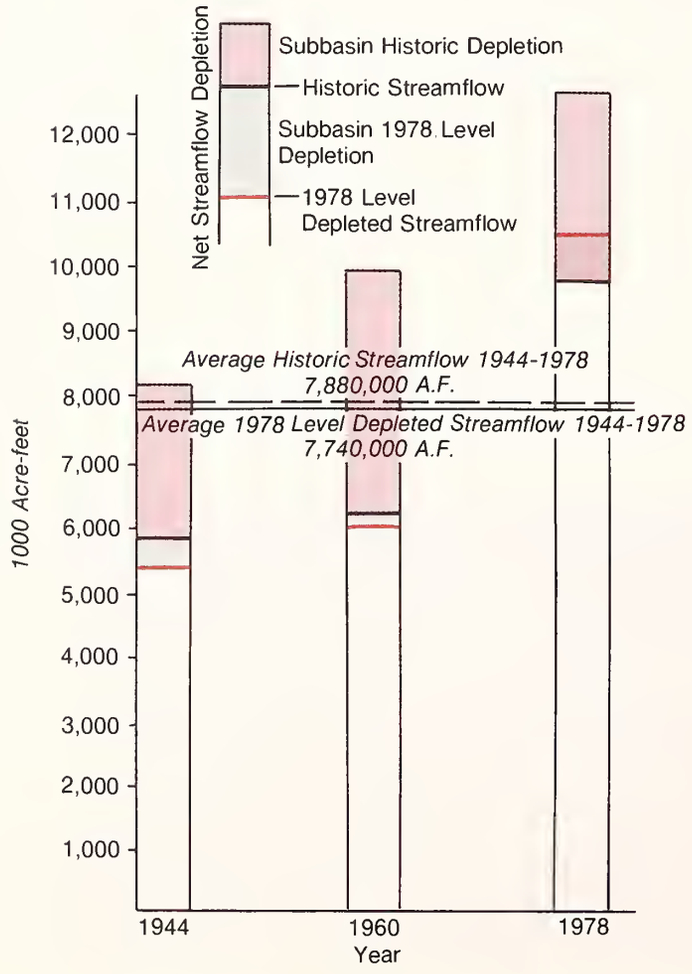
1944 to 1978 period, depletions due to land conservation measures have increased from a .6 percent share to a 1.2 percent share of total depletions. During that period, the acreage of land conservation measures have increased from about 2.5 million acres in 1944 to about 6.4 million in 1978. During this same period, full service irrigated acres increased from 945,000 to 1,131,500 acres, or an increase of about 186,500 acres.

Streamflow accretions due to forest management practices in the subbasin were estimated at 12,200 acre-feet in 1944, increasing to 37,600 acre-feet annually in 1978.

During the 1944 to 1978 period, the population shifted from a primarily rural population of about 176,800, or 68% of the total population, to a more evenly balanced split of 162,400 rural and 141,500 urban.

From 1944 to 1978, total annual depletions in this subbasin increased by about 580,000 acre-feet annually. The increase in total annual depletions between 1960 and 1944, as shown in Figure 20, is attributed to an increase in irrigated acres and water use. Other depletors may have increased their consumption over this period of time also. The decrease in total annual depletions between 1960 and 1978 is attributed to a change in irrigation practices and a decrease in irrigated acres throughout the period of time. As described earlier, the purpose of identifying the water users, estimating depletions over the period 1944 to 1978, and adjusting the historic streamflow to a present level (1978) of development was to determine how much water is yet available for use. A graph of selected years of the 1978 level depleted streamflow is shown on Figure 21. On the average, based on the 1944 to 1978 adjusted streamflow and subject to state water rights, interstate compacts, and instreamflow requirements, 7,740,000 acre-feet annually are available for all non-consumptive and new consumptive users above this stream gage.

Figure 21
Upper Missouri Subbasin
1978 Level Depleted Streamflow
Missouri River at Culbertson, Montana
1944, 1960 and 1978



Yellowstone Subbasin

The Yellowstone Subbasin covers 70,622 square miles in the west central part of the Missouri River Basin, Figure 22. Principal tributaries of the Yellowstone River include the Wind-Bighorn, Powder, Tongue, and the Clarks Fork Rivers. The eastern part of the basin is a region of plateaus, plains, and isolated mountain ranges with elevations from 5,000 to 8,000 feet. Rugged mountains and broad valleys occur in the western and central part of the basin. Plateaus are at the 4,000 feet elevation with peaks to 14,000 feet. A small part of the eastern basin is a relatively smooth plain with elevations from 1,500 to 3,000 feet.

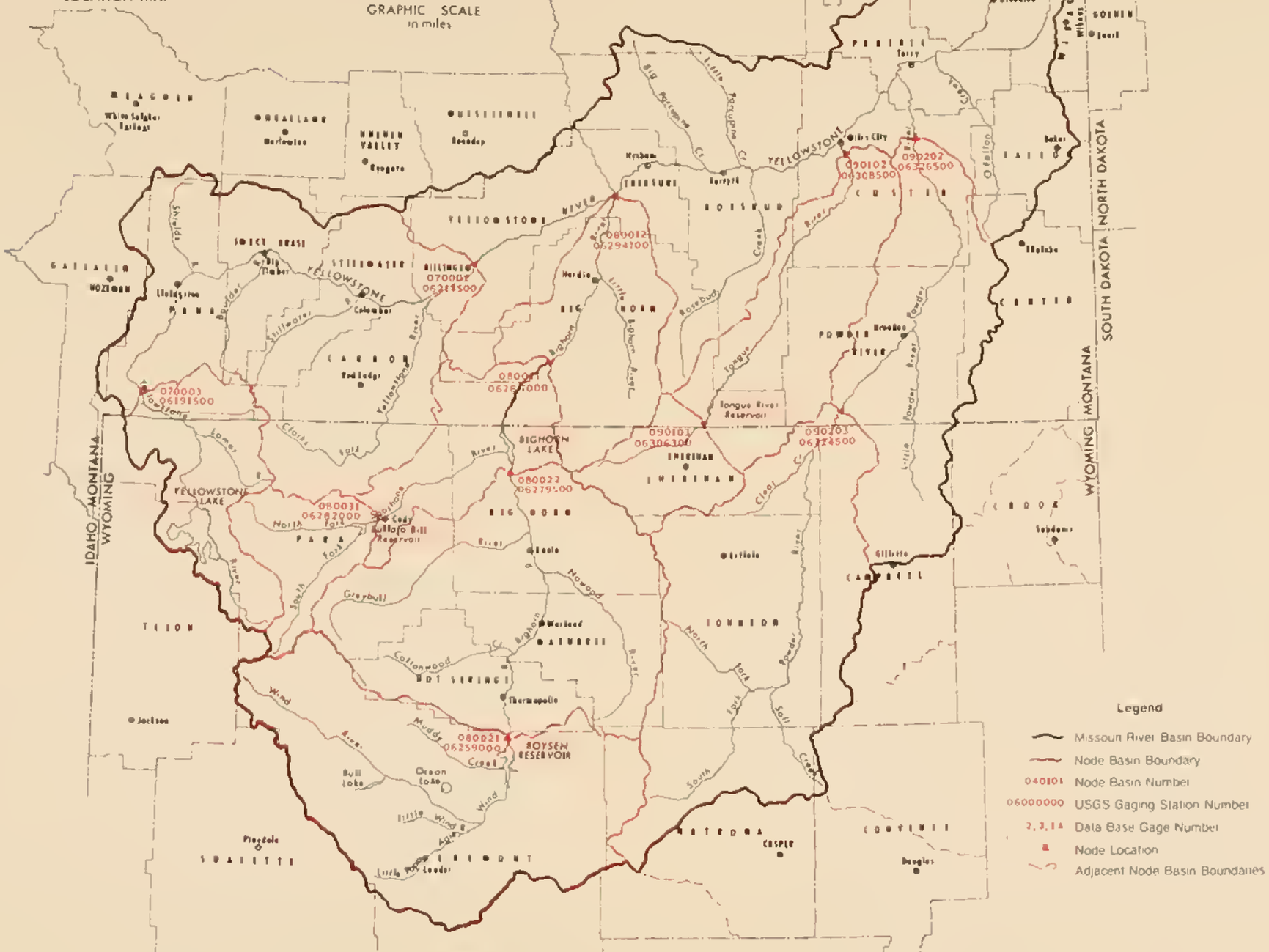
The subbasin area is about evenly split between Wyoming and Montana with a small part, including the rivers confluence with the Missouri River, located in North Dakota.

Grassland is the predominate ecosystem with deciduous woodlands occurring along streams. There are pristine riverscapes with free-flowing streams, high alpine plateaus, scenic canyons, and rugged snow-covered peaks. Ranching is the most important agricultural sector. Tourism is also a very significant sector of the area's economy.

Ground water resources are limited to valley-fill alluvial aquifers along streams. Deep aquifers, such as the Madison, while offering some potential for industrial related developments, are presently not providing signifcant water supplies. Overall, ground water is not an important source of water in the subbasin.

The majority of the surface water originates as mountain snow in the Rocky Mountains. As a result, high flows occur in June and July with low flows in the winter months. The surface water outflow point selected for this subbasin is the USGS gage 06329500 located on the Yellowstone River near Sidney, Montana. The drainage area above that point is 69,103 square miles. For the 1944 to 1978 period of record, the average recorded streamflow at that point was 12,913 c.f.s. or about 9.35 million acre-feet annually.

Figure 22
Yellowstone Subbasin


YELLOWSTONE RIVER
BIGHORN LAKE
YELLOWSTONE LAKE
BOYSEN RESERVOIR
Cody
Buffalo Bill Reservoir
Billings
Miles City
Glendive
Sidney
Hardin
Laurel
Bozeman
Livingston
Big Timber
Red Lodge
Cooke City
Cody
Lovell
Basin
Thermopolis
Worland
Greybull
Lander
Dubois
Jackson
Pinedale
Riverton
Shoshoni
Kaycee
Buffalo
Sheridan
Ranchester
Dayton
Story
Big Horn
Park
Teton
Fremont
Sublette
Lincoln
Sweetwater
Uinta
Carbon
Hot Springs
Washakie
Natrona
Converse
Campbell
Crook
Weston
Niobrara
Goshen
Platte
Powder River
Tongue River Reservoir
Bighorn Lake
Yellowstone River
Big Horn River
Clarks Fork
Shoshone River
North Fork
Greybull River
Wind River
Muddy Creek
Little Wind R.
Little Popo Agie
Bull Lake
Boysen Reservoir
Pilot Butte
Alcova
Casper
Douglas
Glenrock
Orin Junction
Moorcroft
Sundance
Newcastle
Upton
Gillette
Wright
Buffalo
Kaycee
Big Piney
Pinedale
Jackson
Dubois
Lander
Riverton
Shoshoni
Thermopolis
Worland
Basin
Cody
Powell
Lovell
Cowley
Frannie
Deaver
Greybull
Shell
Manderson
Hyattville
Meeteetse
Ten Sleep
Hanover
Kirby
Bonanza
Fort Washakie
Arapahoe
Lysite
Boulder
Big Timber
Reed Point
Columbus
Absarokee
Roberts
Fromberg
Belfry
Bridger
Joliet
Fishtail
Silesia
Park City
Laurel
Huntley
Worden
Ballantine
Custer
Hysham
Forsyth
Rosebud
Colstrip
Broadus
Powderville
Ekalaka
Alzada
Camp Crook
Harrison
Hemingford
Alliance
Crawford
Chadron
Hot Springs
Edgemont
Oelrichs
Hay Springs
Gordon
Rushville
Harrison
Lusk
Manville
Van Tassell
Douglas
Glenrock
Casper
Alcova
Pilot Butte

At the present time, there are no imports or exports of water to or from this subbasin. Three major reservoirs are located within this subbasin, Figure 22. Bighorn Lake behind Yellowtail Dam with a normal capacity of 873,000 acre-feet is the largest, Boysen reservoir with a normal capacity of 802,000 acre-feet is a close second. Buffalo Bill reservoir, located on the Wind River, has a normal capacity of 421,500 acre-feet. All three reservoirs are owned and operated by the U.S. Bureau of Reclamation. Depletions due to evaporation from these reservoirs are shown on Figures 23 through 25. The average monthly evaporation during the peak months of July and August approaches 10,000 acre-feet per month at Boysen reservoir, and 5,000 acre-feet per month at Yellowtail reservoir. The average monthly net evaporation at Buffalo Bill reservoir is about 2,500 acre-feet per month during peak evaporation which occurs in July and August.

In this subbasin, total estimated annual depletions from evaporation from major man-made impoundments averages 129,600 acre-feet annually, while evaporation from all small reservoirs in the subbasin averages about 37,100 acre-feet annually.

Surface water in the three subbasin states is considered public property. The appropriation doctrine is utilized to allocate water in all three states. Under that system, priority in time gives the superior water right. In all three subbasin states, while utilizing somewhat different procedures, state agencies regulate the water right process. Where there are competing applications for water from the same source and there is insufficient water to supply all applicants, the states have established water use preferences. The order of preference differs in the three subbasin states.

Montana, Wyoming and North Dakota are members of the Yellowstone River Compact. Specific allocations of the unused and unappropriated waters of Yellowstone River interstate tributaries (as of January 1, 1950) are set forth under the compact. The unused and unappropriated water is allocated to each state first for supplemental supplies for rights with priorities before January 1, 1950, then for storage or direct diversions for beneficial use. Details of these apportionments can be found in other documents.

In the Yellowstone River basin, the major water user is irrigation. As shown in Figure 26, that activity has accounted for about 90 percent of all depletions in this subbasin. Over the 1944 to 1978 period depletions due to land conservation measures have increased from a 0.5 percent share to a 1.2 percent share of total depletions. This is reflected by the increase in acreage of land conservation measures from about one-half million acres in 1944 to almost 1.4 million acres in 1978. During the period, full service irrigated acres increased from about 972,000 acres in 1944 to a peak of 1,092,000 in the early 1960's. Since then, total full service acres decreased to about 977,000 acres in 1978. Partial service irrigation followed the same pattern

Figure 23
Average Monthly Evaporation
Bighorn Lake (Yellowtail Reservoir)

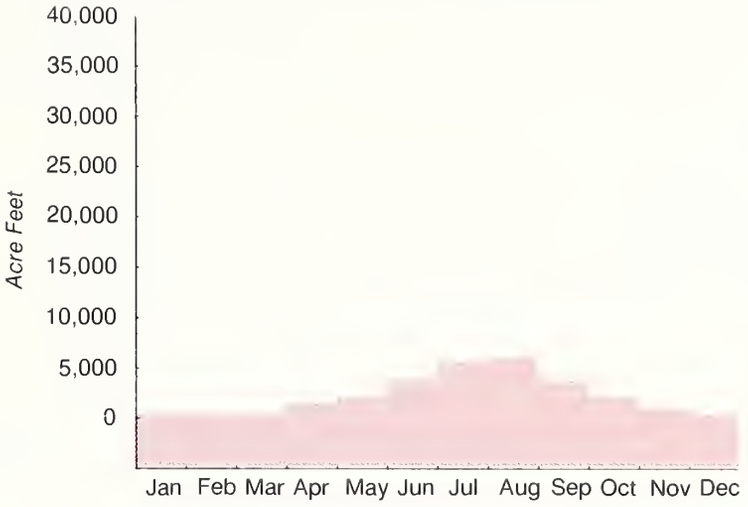


Figure 24
Average Monthly Evaporation
Boysen Reservoir

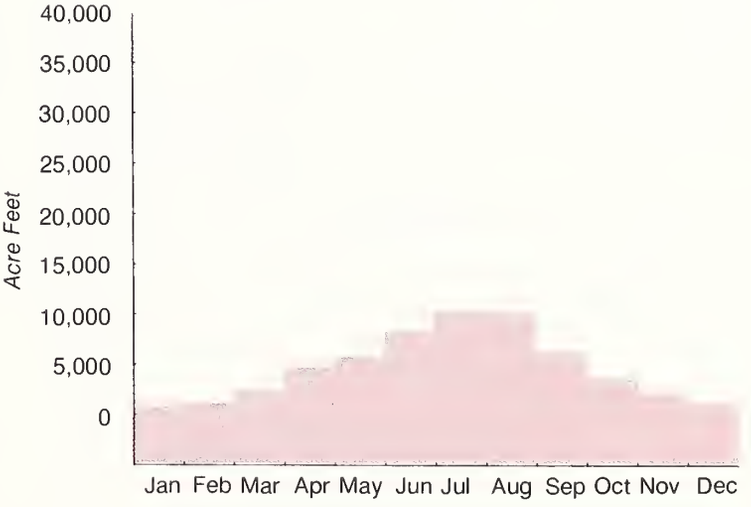


Figure 25
Average Monthly Evaporation
Buffalo Bill Reservoir

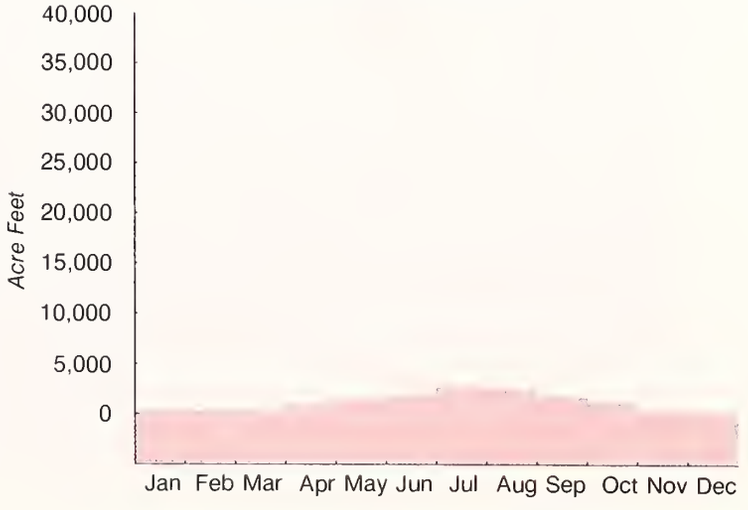
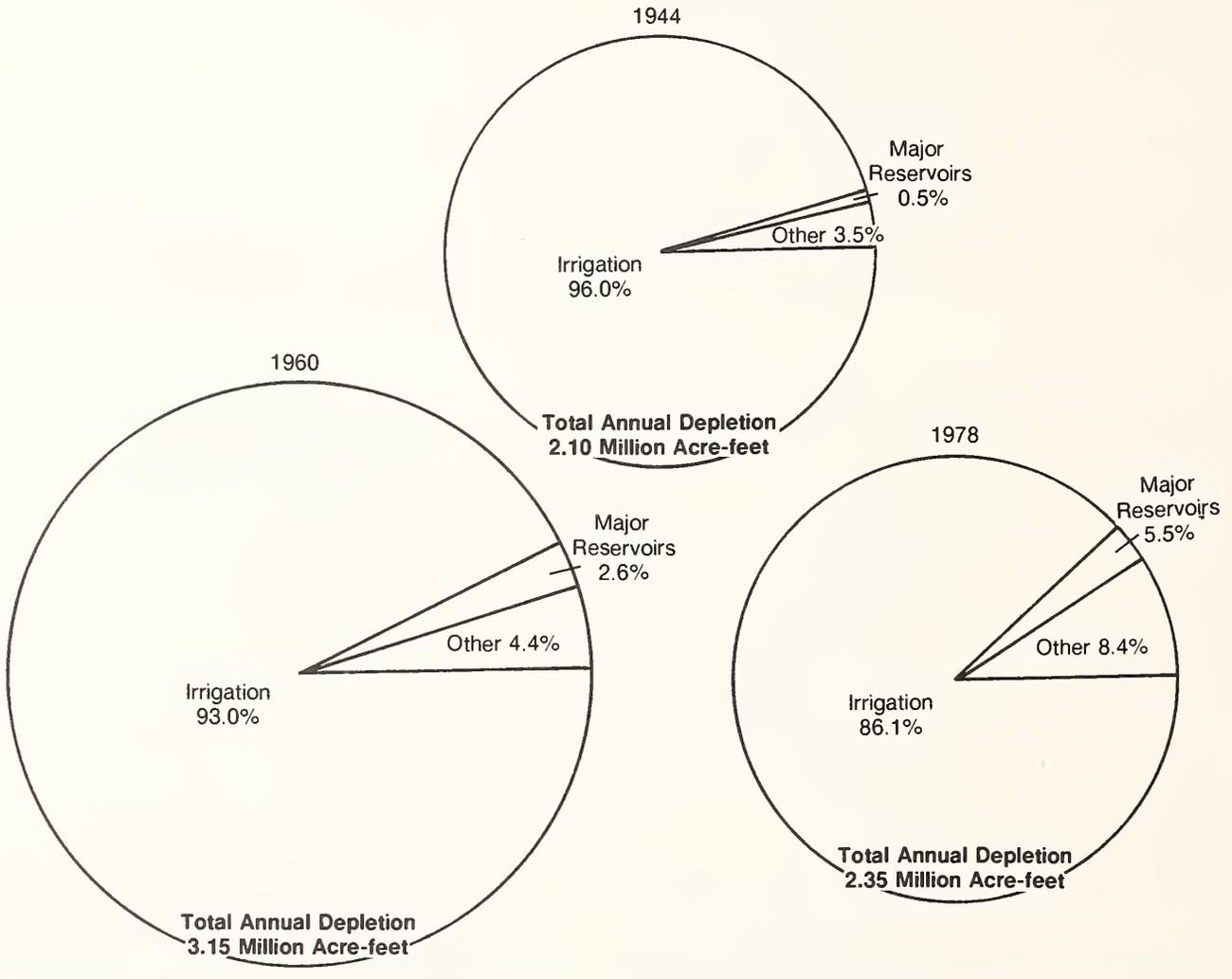


Figure 26
Yellowstone Subbasin
Total Annual Historic Streamflow Depletion by Type of Use 1944, 1960 and 1978



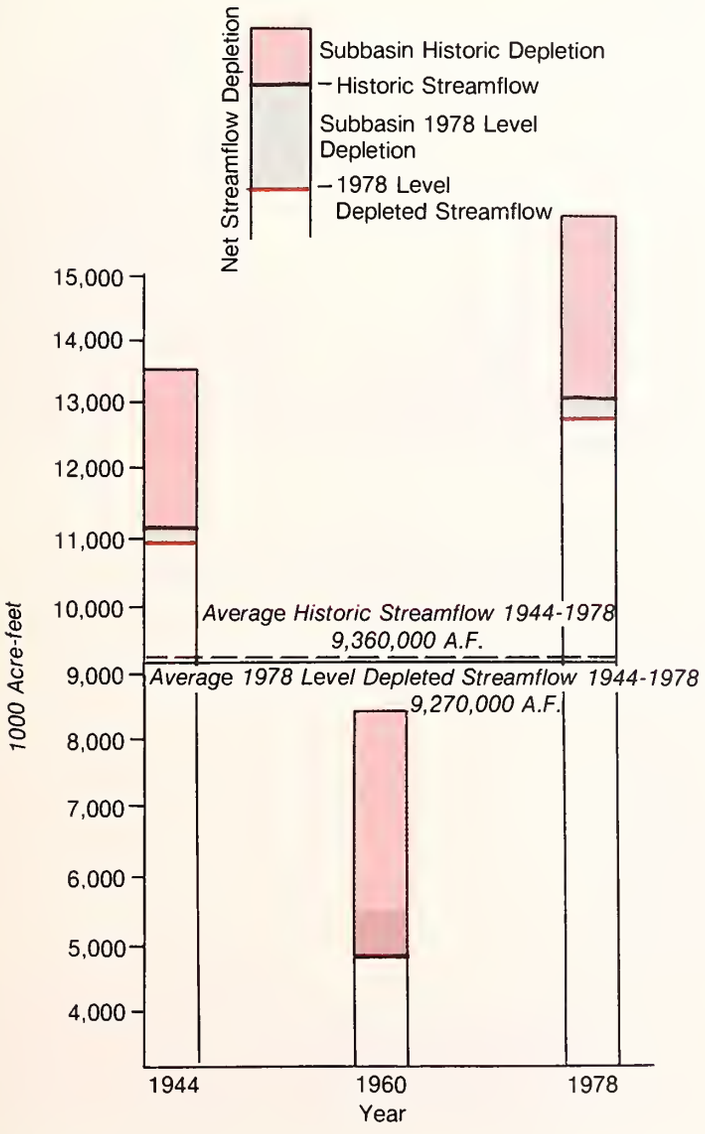
	Other Depletions — Percent of Total		
	1944	1960	1978
Small Reservoirs	1.1	0.9	1.6
Conservation Measures	0.5	0.6	1.2
Farm Ponds	0.8	1.6	3.0
Livestock	0.4	0.2	0.3
Municipal	0.3	0.5	0.9
Industrial	0.1	0.1	0.1
Energy	—	0.2	0.9
Rural Domestic	0.3	0.3	0.4
TOTAL	**3.5**	**4.4**	**8.4**

with about 85,400 acres under irrigation in 1944, reaching a peak of about 96,000 acres by 1964, then decreasing to about 88,300 acres in 1978. Total head of livestock have varied from year to year but in general have steadily decreased a total of about 1 million head over the 1944 to 1978 period.

Streamflow accretions due to forest management practices in the subbasin were estimated at 19,800 acre-feet in 1944 increasing to 44,600 acre-feet annually in 1978.

During the 1944 to 1978 period, the population shifted from a primarily rural population of about 126,400, or 62% of the total population, to a primarily urban population with 130,700 rural and 161,402 urban. This change in population reflects the growth due to energy development in the subbasin.

Figure 27
Yellowstone Subbasin
1978 Level Depleted Streamflow
Yellowstone River near Sidney, Montana
1944, 1960 and 1978



From 1944 to 1978, total depletions increased only by about 250,000 acre-feet, however, during 1960, total depletions were about 800,000 acre-feet above the 1978 level. The decrease in total annual depletions between 1960 and 1978 is attributed to a change in irrigation practice and a decrease in irrigated acres throughout the period of time.

A graph of selected years of the 1978 level depleted streamflow is shown on Figure 27. On the average, based on the 1944 to 1978 adjusted streamflow and subject to state water rights, interstate compacts and instreamflow requirements, 9,270,000 acre-feet annually are available for all non-consumptive and new consumptive uses above this stream gage.

Western Dakotas Subbasin

The Western Dakotas Subbasin covers 77,119 square miles in the north central part of the Missouri River basin, Figure 28 (page 33).

Principal tributaries to the Missouri River include the Little Missouri, Knife, Heart, Cannonball, Grand, Moreau, Cheyenne, Bad and White Rivers. The topography is rolling with elevations averaging 2,000 feet. The Black Hills of South Dakota and the Badlands of North Dakota are two unique topographic areas in the subbasin. The majority of the subbasin is of a prairie grassland ecosystem. Extensive dryland farming of the crop fallow type have developed in western North Dakota.

The majority of the subbasin area is located in North and South Dakota. Small parts are also located in Montana, Wyoming and Nebraska. Ranching and farming are the predominate economic sectors. Tourism is also an important sector of the economy. The production of energy fuels from coal and lignite deposits, as well as the production of crude oil and natural gas provide significant economic activity. Gold mined in the Black Hills accounts for a high percent of the national production. Ground water resources are limited and generally are of poor quality.

Surface water supplies in the tributary streams are the result of spring snow melt and summer thundershowers. As a result, streamflows in the tributary streams are extremely variable from year to year. The surface water outflow point selected for this subbasin is the USGS gage number 06453000 located on the Missouri River at Fort Randall Dam, South Dakota. The drainage area above that point is approximately 263,500 square miles. For the 1944 to 1978 period of record, the average recorded streamflow at that point was about 25,614 c.f.s., or 18.6 million acre-feet annually.

At this time there are no imports or exports of water to or from this subbasin.

Four major reservoirs have been constructed in the subbasin, all on the Missouri main stem. In terms of normal capacity the Oahe reservoir at 19.3 million acre-feet is the largest. Garrison Dam and its Lake

Sakakawea with a normal capacity of 18.6 million acre-feet is a close second. Fort Randall Dam and its Lake Francis Case and Big Bend Dam and its Lake Sharpe have normal capacities of 3.4 million and 1.7 million acre-feet, respectively. These four reservoirs are operated by the Corps of Engineers as a part of their Missouri main stem operation. Evaporation from these reservoirs is the major depletor of water in the subbasin. As shown in Figure 29 and Figure 30, net evaporation during the peak month of September approaches 130,000 acre-feet at both the Garrison and Oahe reservoirs. Net evaporation at Fort Randall reservoir, during the same month, is approximately 35,000 acre-feet, Figure 31.

In this subbasin, total depletions from evaporation from major man-made impoundments averages 1,172,100 acre-feet annually, while evaporation from all small reservoirs in the subbasin averages about 246,200 acre-feet annually. For purposes of this study, evaporation from the reservoir behind Big Bend Dam is included with small reservoirs.

Water in all the subbasin states is considered public as described in other sections of this report. In South Dakota, as in some other states, beneficial use is the basis, measure and the limit of the right to use. The right to surface water is made by application to the Water Resources Commission. There are no explicit statutory provisions in South Dakota for the appropriation of instream flows. In 1943 the States of South Dakota and Wyoming concluded a compact to provide for efficient use and equitable division of the waters of the Belle Fourche River.

In the Western Dakotas Subbasin, the two major water users are evaporation from major reservoirs and irrigation. Small reservoirs and farm ponds are also significant depletors. As shown in Figure 32, these evaporations from major reservoirs and irrigation have accounted for over 75 percent of all depletions in this subbasin since the construction of the Missouri main stem reservoir system. Over the 1944 to 1978 period, depletions due to small reservoirs have also increased significantly. This is, however, largely due to accounting for the Big Bend Reservoir on the Missouri main stem within that category. During the 1944-1978 period, full service irrigated acres increased from about 83,000 acres to over 323,000 acres. Partial service irrigation also increased during that period from about 6,000 acres to 20,100 acres. During the 1944-1978 period, there was an almost 10-fold increase in water-spreader irrigation from 14,100 acres to 139,500 acres. Although, by percent, irrigation increased dramatically, the total acres irrigated are still low and total depletions due to all types of irrigation accounted for only about 27 percent of the total depletions in 1978.

During the 1944 to 1978 period, the population shifted from a primarily rural population of 352,900, or 81% of the total population, to a more evenly although predominately rural split of 284,000 rural and 195,200 urban.

Figure 29
Average Monthly Net Evaporation
Lake Sakakawea (Garrison Reservoir)

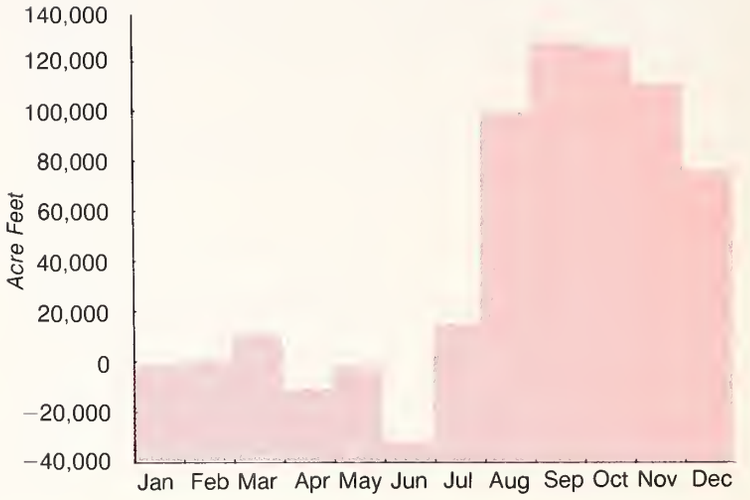


Figure 30
Average Monthly Net Evaporation
Oahe Reservoir

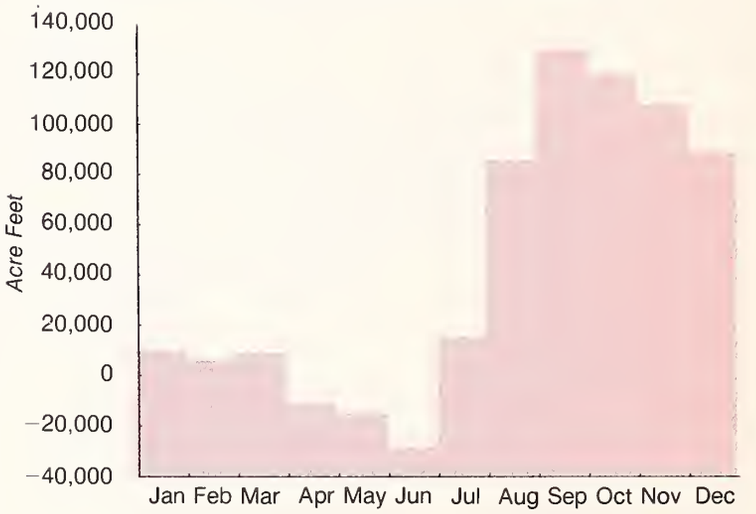
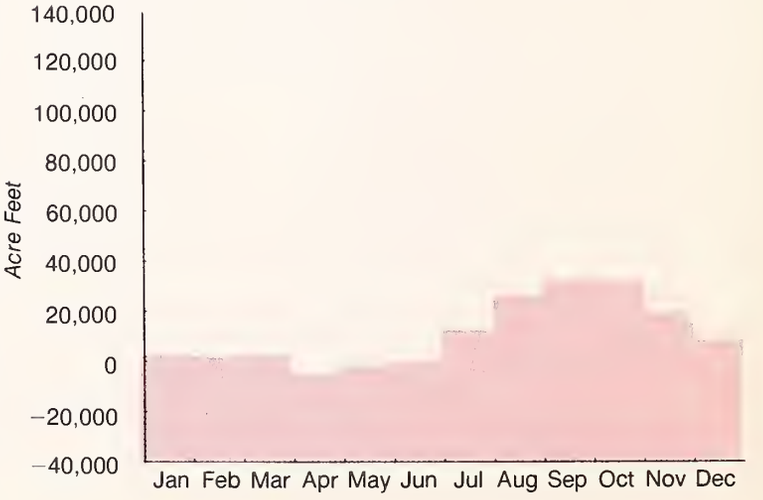


Figure 31
Average Monthly Net Evaporation
Lake Francis Case (Fort Randall Reservoir)



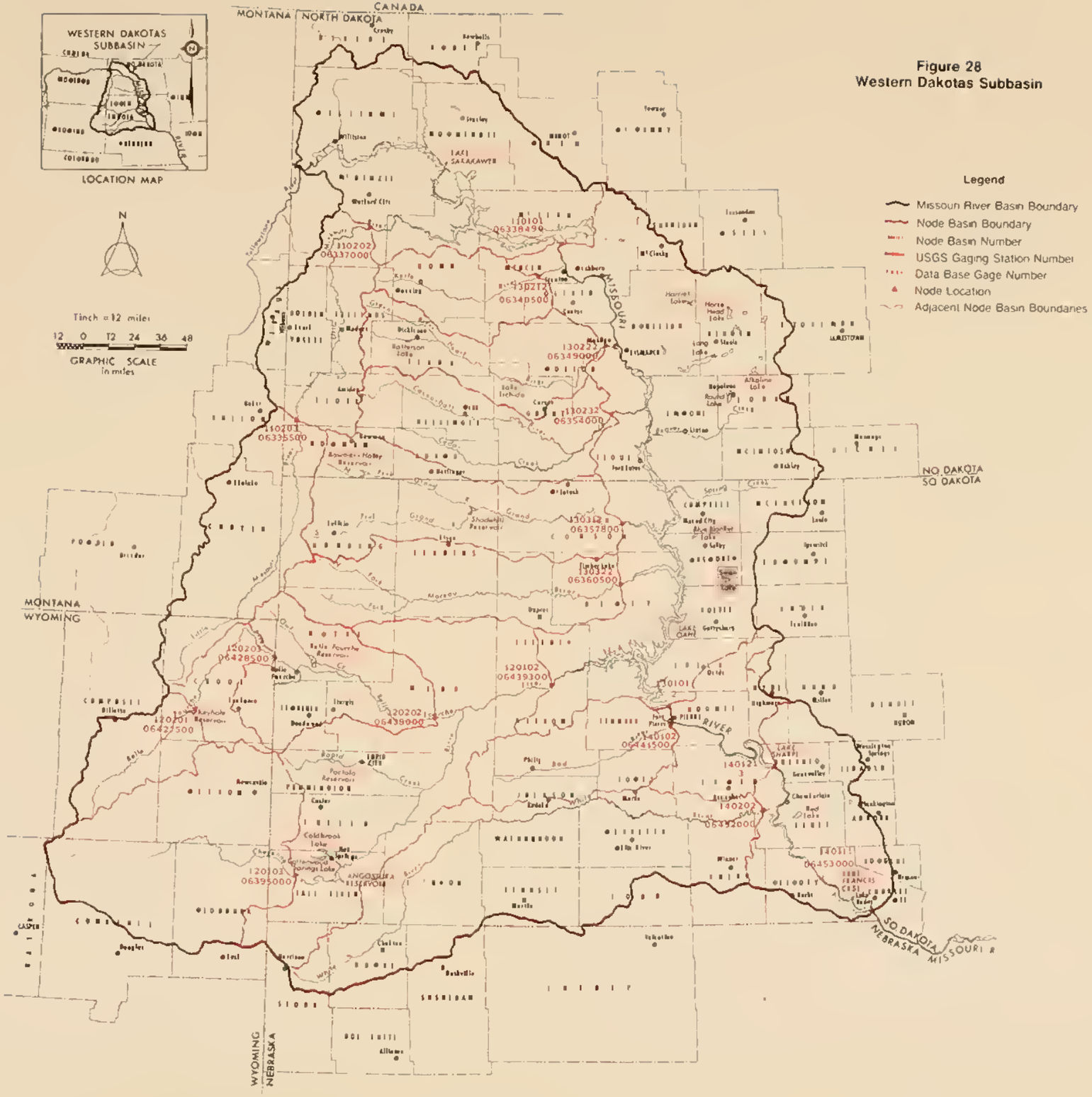
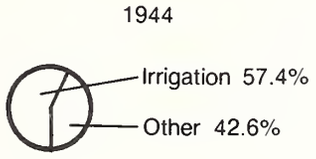
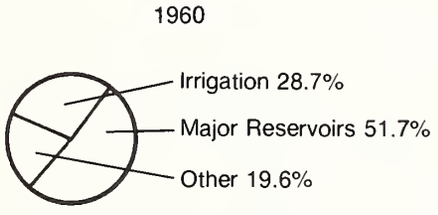


Figure 28
Western Dakotas Subbasin

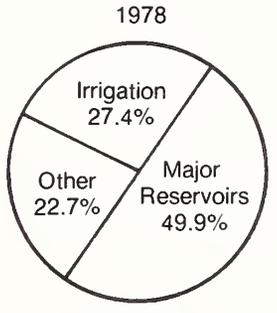
Figure 32
Western Dakotas Subbasin
Total Annual Streamflow Depletion
by Type of Use
1944, 1960 and 1978



Total Annual Depletion
0.27 Million Acre-feet



Total Annual Depletion
1.26 Million Acre-feet



Total Annual Depletion
2.35 Million Acre-feet

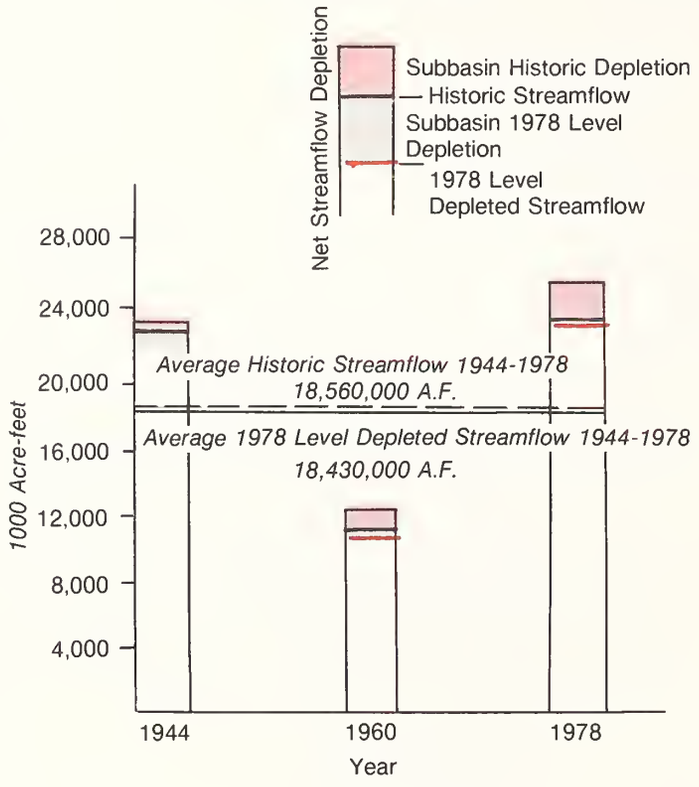
Other Depletions - Percent of Total

	1944	1960	1978
Small Reservoirs	9.1	4.7	10.5
Conservation Measures	5.7	2.3	1.7
Farm Ponds	14.7	8.7	6.7
Livestock	6.5	1.5	0.8
Municipal	1.6	0.9	0.8
Industrial	1.1	0.2	0.1
Energy	0.1	0.3	1.5
Rural Domestic	3.8	1.0	0.6
TOTAL	**42.6**	**19.6**	**22.7**

From 1944 to 1978 total annual depletions increased in this subbasin by about 2.08 million acre-feet. The majority of that is attributed to evaporation from the main stem Missouri reservoir system.

A graph of selected years of the 1978 level depleted streamflow is shown on Figure 33. On the average, based on the 1944 to 1978 adjusted streamflow and subject to state water rights, interstate compacts, and instreamflow requirements, 18,430,000 acre-feet are available for all non-consumptive and new consumptive uses above this stream gage.

Figure 33
Western Dakotas Subbasin
1978 Level Depleted Streamflow
Missouri River at Fort Randall Dam, South Dakota
1944, 1960 and 1978



Eastern Dakotas Subbasin

The Eastern Dakotas Subbasin covers 58,288 square miles in the northeastern part of the Missouri River basin, Figure 34. The principal river is the James, with the Vermillion and Big Sioux also important tributaries to the Missouri River. The most striking feature of the subbasin is its flatness. The stream gradient of the James River in the central part of the basin averages about .05 feet per mile.

The majority of the subbasin lies in North and South Dakota with small areas in Minnesota, Nebraska and Iowa.

The predominate ecosystem is agricultural with small grains, row crops and pasture providing the majority of the land cover. Limited areas of native prairie do however still exist. Woodlands are limited to farmstead shelterbelts or along streams. In this subbasin farming dominates the economy.

The ground water source is somewhat limited in this subbasin and the quantity of ground water varies from aquifer to aquifer. Irrigation is the major user of ground water in the subbasin.

Surface water originates as snow cover or as spring and summer thunderstorms. As is typical in areas of continental climates, precipitation is highly variable over the seasons and from year to year. The point selected as the surface water outflow point for this subbasin is the USGS gage number 06486000, Missouri River at Sioux City, Iowa. The drainage area above that point is approximately 314,600 square miles. For the 1944 to 1978 period of record, the average recorded streamflow at that point was 30,063 c.f.s., or about 21.8 million acre-feet annually. However, the majority of that flow comes from the upper reaches of the Missouri River as the average flow of the James River near Scotland, South Dakota, is only 276,000 acre-feet annually.

Presently there are no imports or exports to or from this subbasin. One major reservoir is located in the subbasin, that is Gavins Point Dam and its reservoir, Lewis and Clark Lake. The reservoir, with a normal capacity of 360,000 acre-feet, is the smallest of the six Missouri main stem reservoirs operated by the Corps of Engineers. It is also the furtherest downstream of the Missouri River reservoirs on the main stem.

Net evaporation from the surface of Lewis and Clark Lake is estimated to average 41,300 acre-feet per year.During the July to October period monthly net evaporation from that reservoir is approximately 7,000 acre-feet per month, as shown in Figure 35. Evaporation from all small reservoirs in the subbasin averages about 22,800 acre-feet annually.

As described earlier, water in the States of North and South Dakota is considered public and is appropriated under state permitting processes.

In the Eastern Dakotas Subbasin, for 1978, the major water user was irrigation which accounted for over 67 percent of the total streamflow depletions, Figure

Figure 35
Average Monthly Net Evaporation
Lewis and Clark (Gavins Point Reservoir)

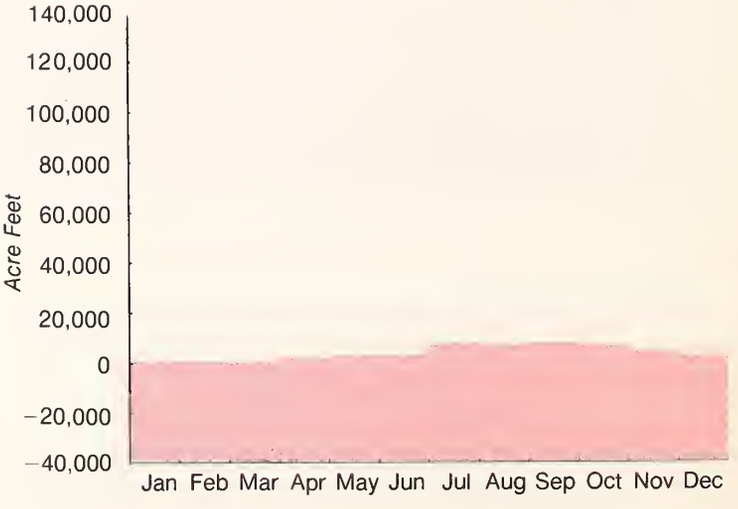


Figure 34
Eastern Dakotas Subbasins

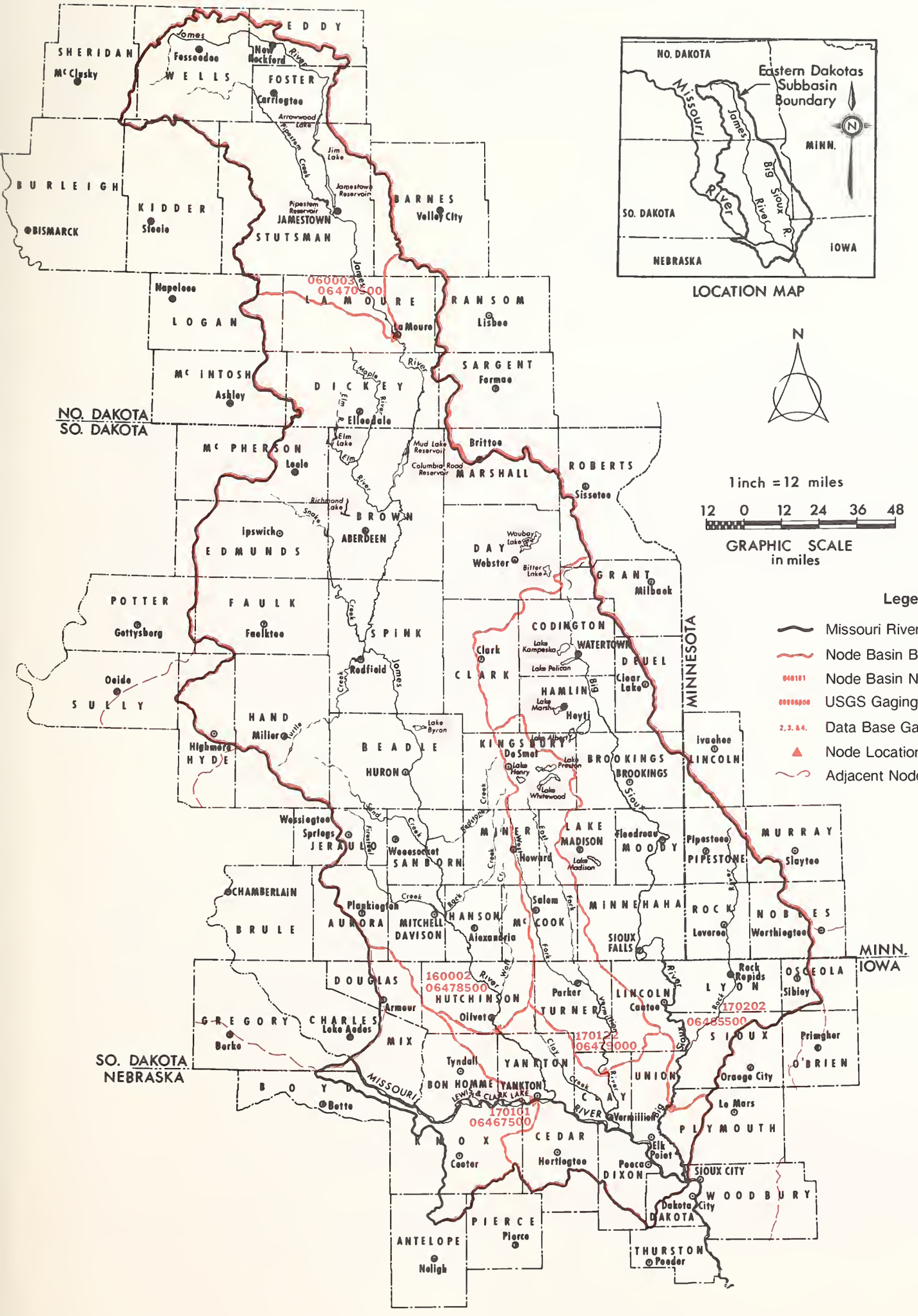
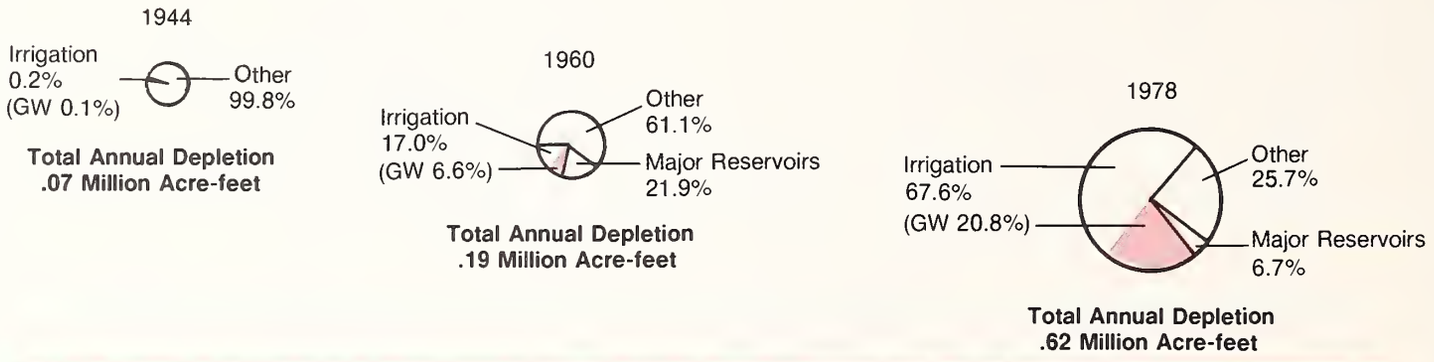


Figure 36
Eastern Dakotas Subbasin
Total Annual Historic Streamflow Depletion
by Type of Use
1944, 1960 and 1978



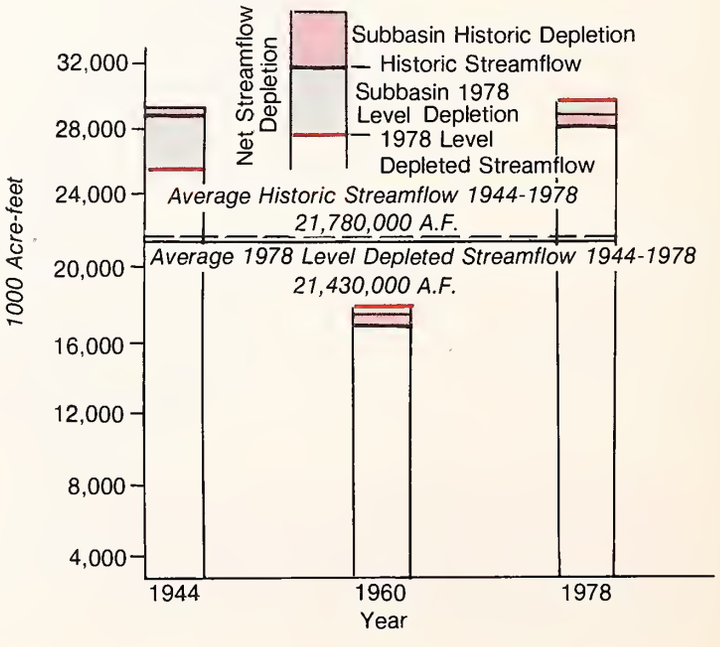
Other Depletions - Percent of Total			
	1944	1960	1978
Small Reservoirs	24.5	11.1	3.7
Conservation Measures	13.8	15.2	8.5
Farm Ponds	9.0	10.0	4.4
Livestock	24.7	10.4	3.4
Municipal	12.6	6.9	3.0
Industrial	0.2	0.1	0.2
Energy	0.0	0.1	—
Rural Domestic	15.0	7.3	2.5
TOTAL	**99.8**	**61.6**	**25.7**

36. Total streamflow depletions from irrigation in the subbasin increased from only two-tenths of a percent in 1944 to over 67 percent in 1978. During that period irrigated acres using surface water sources increased from only 160 acres in 1944 to over 262,000 acres by 1978. Rural domestic use declined over that same period with the population shifting from predominately rural to a more even split of 323,200 rural and 244,800 urban in 1978. The percent of the total depletions due to conservation measures increased in the 1944 to 1960 period, then decreased to 1978. That decrease in percent of total was a result of the increased use for irrigation.

From 1944 to 1978, total annual surface water depletions increased by only about 0.55 million acre-feet in the subbasin. The majority of that increase was due to the increase in irrigated acres within the subbasin.

A graph of selected years of the 1978 level depleted streamflow is shown on Figure 37. On the average, based on the 1944 to 1978 adjusted streamflow and subject to state water rights, interstate compacts, and instreamflow requirements, 21,430,000 acre-feet are available for all nonconsumptive and new consumptive uses above this stream gage.

Figure 37
Eastern Dakotas Subbasin
1978 Level Depleted Streamflow
Missouri River at Sioux City, Iowa
1944, 1960 and 1978



Platte-Niobrara Subbasin

The Platte-Niobrara Subbasin covers 99,492 square miles in the southwest and central part of the Missouri River basin, Figure 38. The Platte River is formed by the joining of the South Platte River flowing out of northeastern Colorado and the North Platte River flowing out of southeastern Wyoming. Those two rivers join near North Platte, Nebraska to form the Platte River. Other important Platte River tributaries include the Loup and Elkhorn Rivers in eastern Nebraska. The Niobrara River is a tributary to the Missouri located in extreme northern Nebraska. The majority of the subbasin is located in the three states of Colorado, Wyoming and Nebraska. A small part of the subbasin is located in southwestern South Dakota.

The topography is highly varied. In the west the Rocky Mountain Continental Divide in Colorado and Wyoming forms the western boundary. Eastward, foothills and high plains are the predominate land forms. The sandhill terrain of western Nebraska with its large ranches is in itself a unique area within the Missouri River basin. Central and eastern Nebraska on the other hand is an area of intensive agricultural land use with corn the predominate crop. The subbasin stretches about 600 miles in the east-west direction and about 300 miles, at its widest point, in the north and south direction.

Ground water is an extremely important source of water supply in this subbasin. The gigantic High Plains Aquifer covers most of Nebraska as well as part of the subbasin in Wyoming, Colorado and South Dakota. Extensive development of ground water, as described later, has occurred in this subbasin.

As can be expected in an area with this diverse topography, surface water supplies are highly variable across the subbasin. In the west runoff from winter snow melt provides the majority of the water supply. Across the basin the dry continental climate provides from about 16 to 28 inches mean annual precipitation, with the eastern side of the basin receiving the higher precipitation rates.

For this subbbasin, the point selected as the surface water outflow point was the USGS gage 06805500, Platte River at Louisville, Nebraska. The drainage area above that point is approximately 85,800 square miles. For the 1944 to 1978 period of record, the average recorded streamflow of that point was 6,040 c.f.s., or 4.4 million acre-feet annually. For the Niobrara River, the point selected as the surface water outflow point was the USGS gage 06465000, Niobrara River near Spencer, Nebraska. The drainage area above that point is approximately 12,100 square miles. For the 1944 to 1978 period of record, the average recorded streamflow of that point was 1460 c.f.s., or 1.1 million acre-feet annually.

A number of projects have been developed in the Colorado part of the subbasin for the import of water to the subbasin. The general location of those projects are shown on Figure 38.

The Little Snake River diversion imports water from the Colorado River Basin to Cheyenne, Wyoming. Annual imports since 1964 have ranged from about 4,200 to 9,500 acre-feet per year, Figure 39. The Grand River Ditch has operated over the entire 1944 to 1978 study period. This Ditch imports water from tributaries to the north fork of the Colorado River to the La Poudre Pass Creek, a tributary to the Cache La Poudre River in Colorado. Imports over the 35 year period have ranged from about 9,500 to about 26,000 acre-feet per year, Figure 40.

Figure 39
Annual Water Import
Little Snake River Diversions
to Cheyenne Water Supply, Wyoming

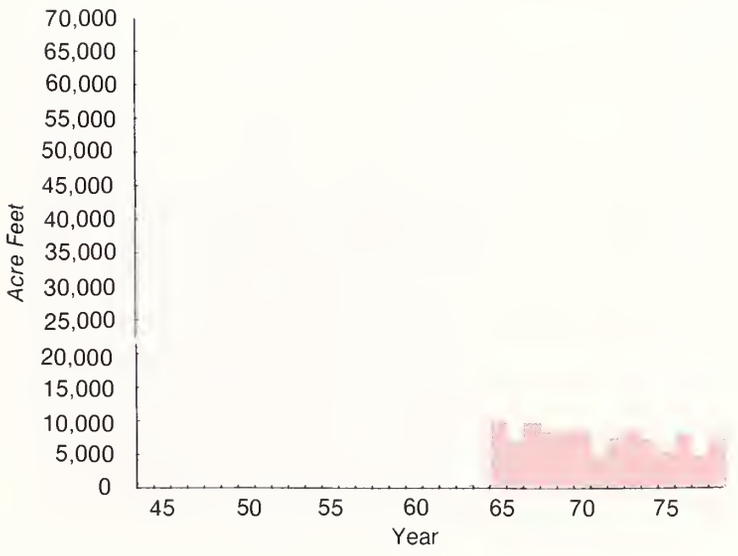
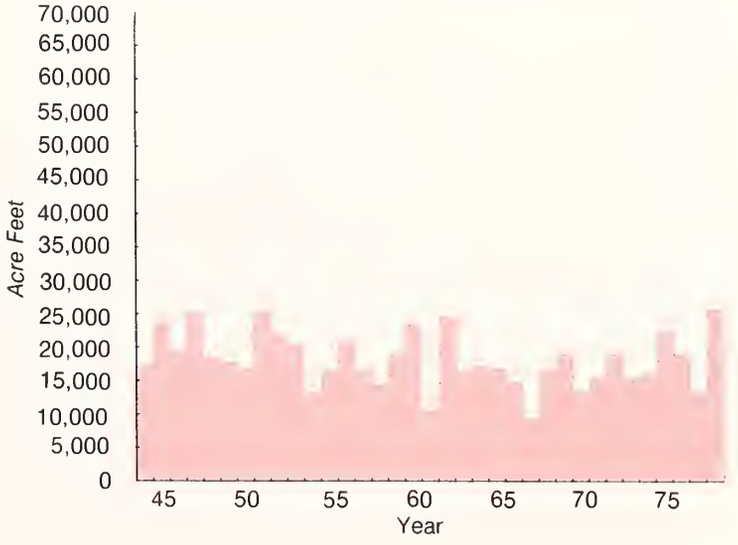


Figure 40
Annual Water Import
Grand River Ditch, Colorado



The Alva B. Adams Tunnel also imports water from the north fork of the Colorado River but in this case to the Big Thompson River in Colorado. Imports have varied over the period but since the 1950's have ranged from 175,000 to nearly 325,000 acre-feet annually, Figure 41. This is the largest project for importation of water in the Missouri River basin.

The Moffat Tunnel imports water from the Fraser and Williams Fork Rivers, tributaries of the Colorado River, to South Boulder Creek, located in the South Platte River basin in Colorado. The project has been in operation over the entire study period 1944 to 1978. Annual imports have varied widely over the time period with a range from about 15,000 to about 80,000 acre-feet per year, Figure 42.

The Aurora-Homestake Pipeline imports water from the headwaters of the Eagle River, a tributary of the Colorado River, to the Arkansas River and then to the south fork of the South Platte River in Colorado. Imports began in the mid-60's and have ranged from about 2,500 to over 13,500 acre-feet annually, Figure 43.

Roberts Tunnel imports water from the Blue River in the Colorado basin to the north fork of the South Platte in Park County. Imports began in the early 1960's and have varied over the years, as shown in Figure 44.

Transfers of water around node basin outflow points within a given subbasin, while having little impact on the overall water supply available for the subbasin as

Figure 41
Annual Water Import
Alva B. Adams Tunnel, Colorado

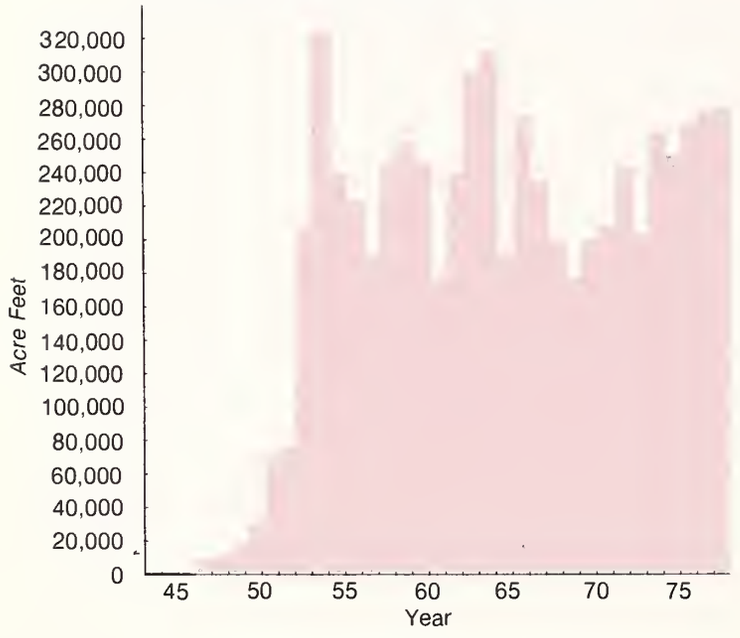


Figure 42
Annual Water Import
Moffat Tunnel, Colorado

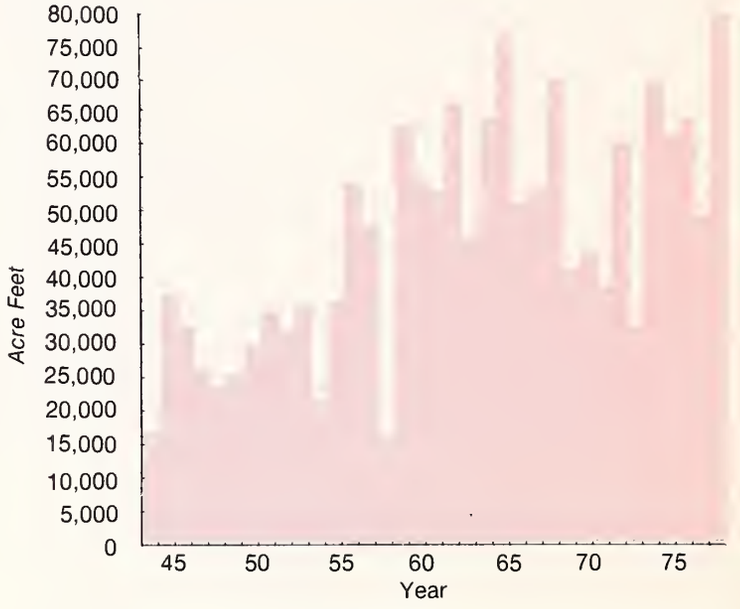


Figure 43
Annual Water Import
Aurora-Homestake Pipeline, Colorado

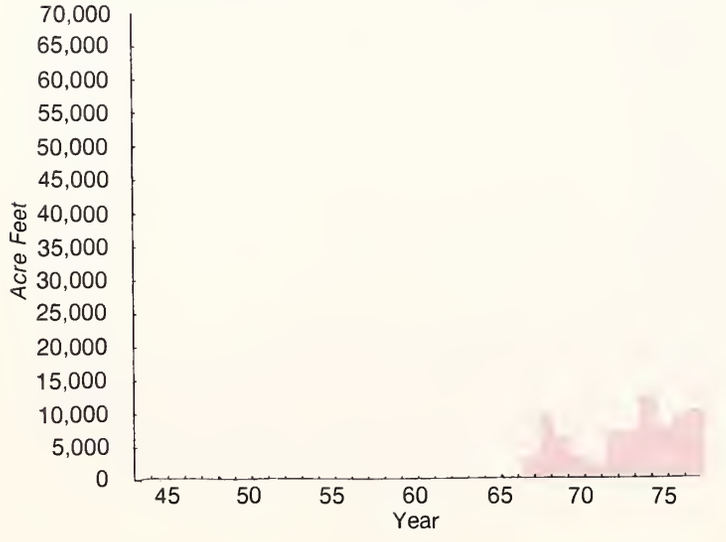


Figure 44
Annual Water Import
Roberts Tunnel, Colorado

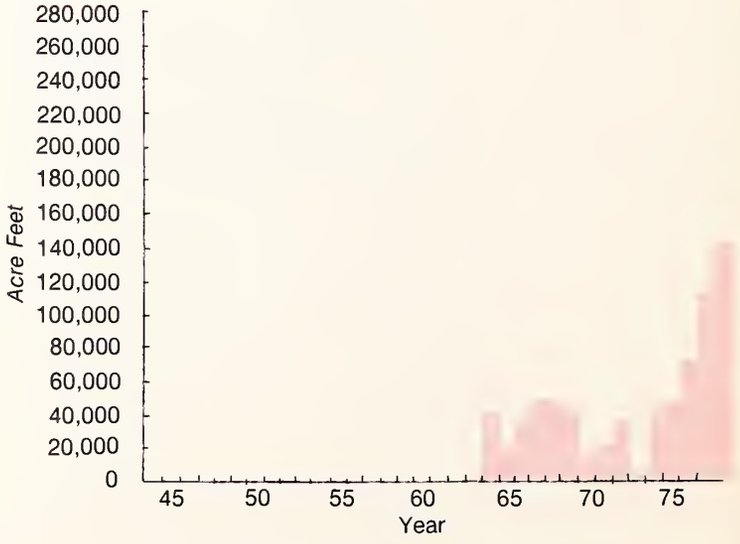
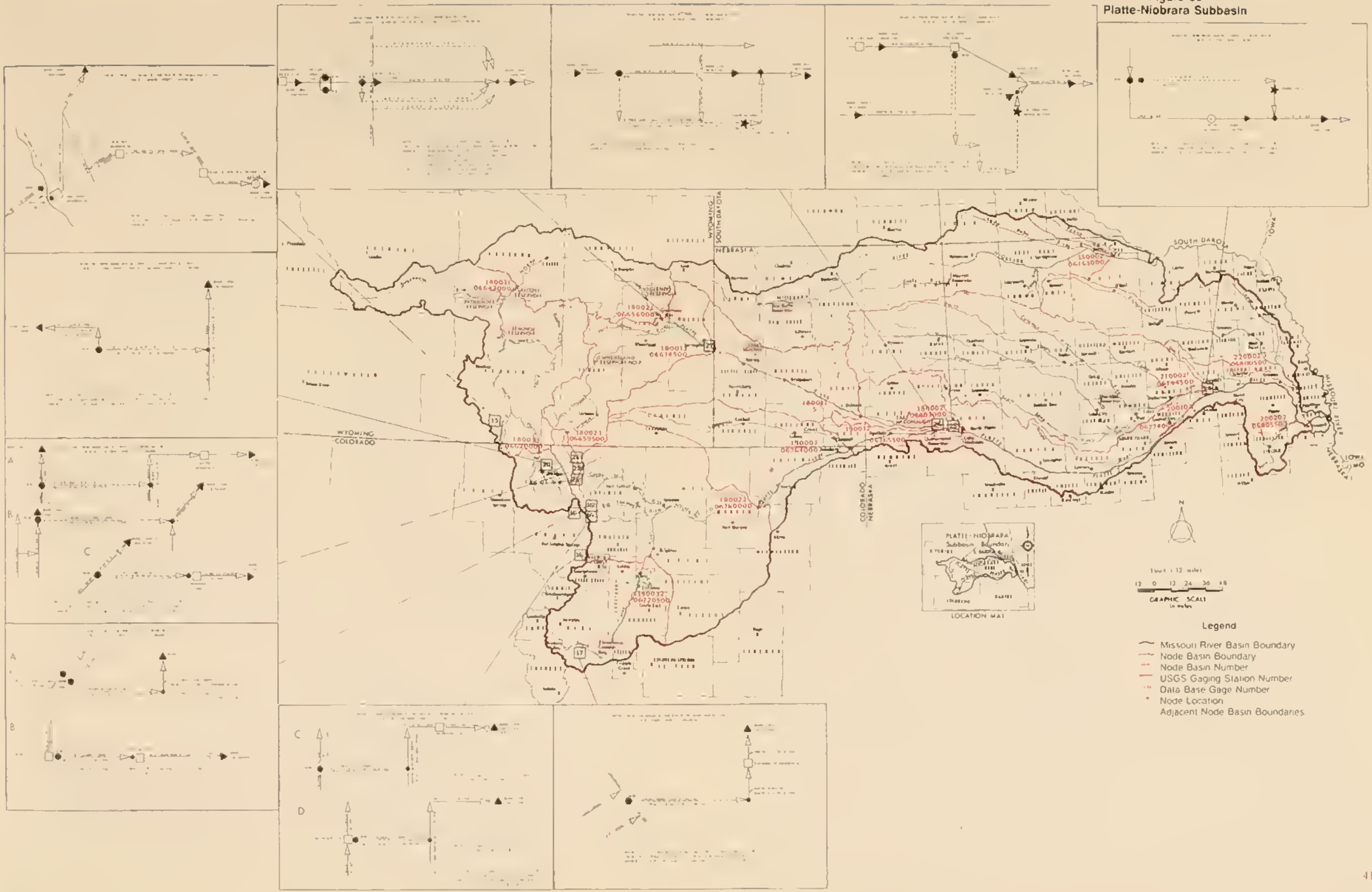


Figure 38
Platte-Niobrara Subbasin



a whole, do have major impacts on the water supply from one node basin to the next node downstream. In the Hydrology Study, such transfers of water were accounted for. The locations of those projects in this subbasin are also shown on Figure 38.

Several such node basin transfers occur in the Platte River Subbasin. The Michigan Ditch is one such transfer. It transfers water from the Michigan River, a tributary to the North Platte River into the Joe Wright Creek, a tributary to the Cache La Poudre River. Annual transfers vary from year to year and have ranged from zero to about 4,200 acre-feet over the 1944 to 1978 study period, Figure 45.

The Skyland Ditch transfers water from the west branch of the Laramie River to Chambers Lake on the Cache La Poudre River. Transfers have ranged from near zero to about 11,000 acre-feet annually, Figure 46. The Laramie-Poudre Tunnel transfers water from the Laramie River to the Cache La Poudre River with transfers from about 9,000 to over 19,000 acre-feet annually, Figure 47.

The Wilson Supply Ditch transfers water from Sand Creek, a tributary of the Laramie River to Sheep Creek, a tributary to the north fork of the Cache La Poudre River. Water transfers have ranged from about 1,000 to over 5,500 acre-feet per year, Figure 48.

Figure 45
Annual Water Diversion
Michigan Ditch, Colorado

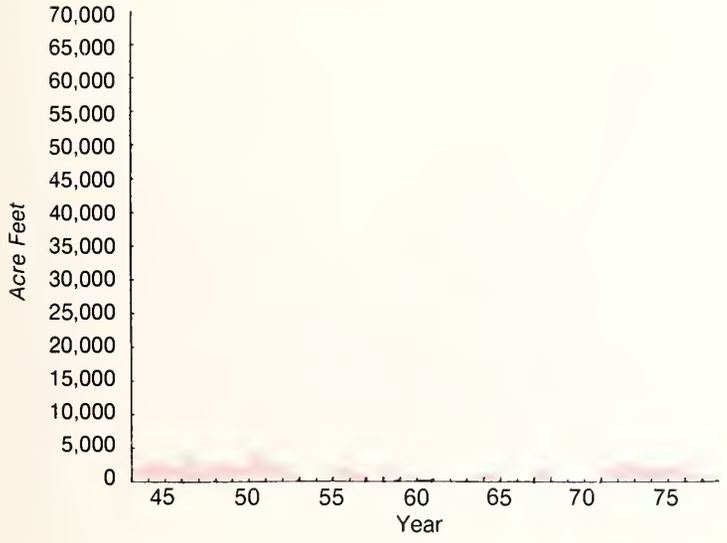


Figure 46
Annual Water Diversion
Skyline Ditch, Colorado

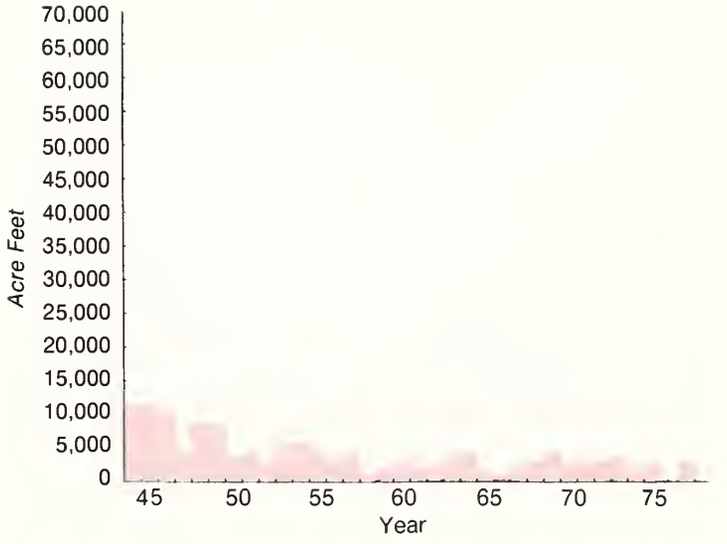


Figure 47
Annual Water Diversion
Laramie-Poudre Tunnel, Colorado

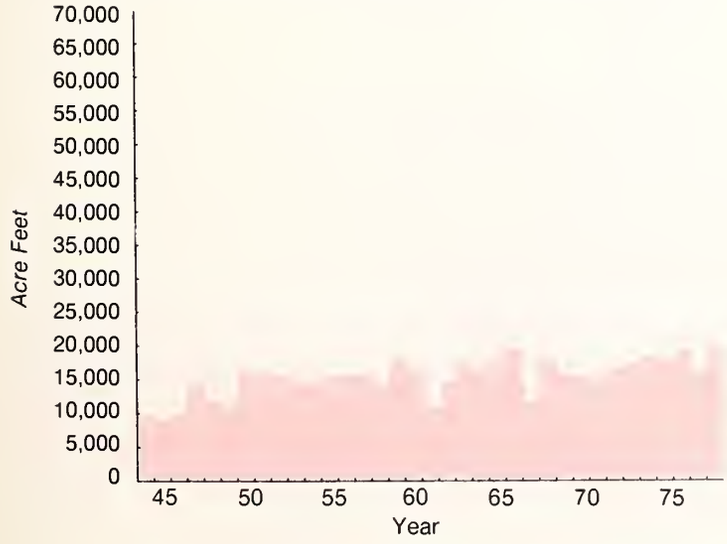
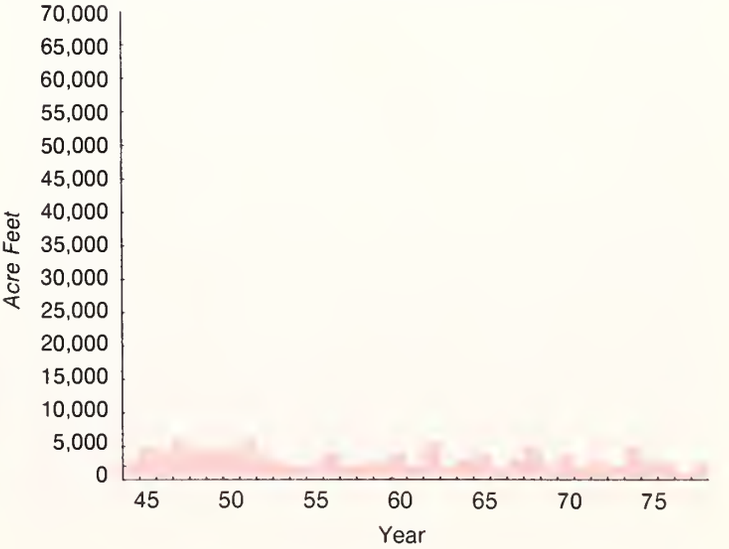


Figure 48
Annual Water Diversion
Wilson Supply Ditch, Colorado



The Loup River Power Canal transfers water from the Loup River to the Platte River. This canal transfers the largest quantity of water in the Missouri River basin. Water transfers have ranged from about 1 million acre-feet to 1.4 million acre-feet annually, Figure 49.

The Sutherland Canal transfers water from the North Platte River below Kingsley Dam to the South Platte River. Transfers of water in this canal have ranged from about 300,000 to 950,000 acre-feet annually, Figure 50. The Sutherland Canal, Korty Diversion, from the South Platte to the Sutherland Canal began operation about 1946. Transfers of water in that canal have ranged from about 25,000 to nearly 450,000 acre-feet per year, Figure 51.

A complex transfer of water occurs from the Whalen Diversion Dam in Wyoming, across the Wyoming-Nebraska stateline in the North Platte drainage area. Three canals, the Interstate Canal, The Gering-Mitchell Canal and the Laramie Canal are a part of this system. Total diversions from these three canals have ranged from about 490,000 acre-feet to over 1 million acre-feet annually. Annual diversions for these canals are shown in Figure 52 through Figure 54.

Figure 49
Annual Water Diversion
Loup River Power Canal near Genoa, Nebraska

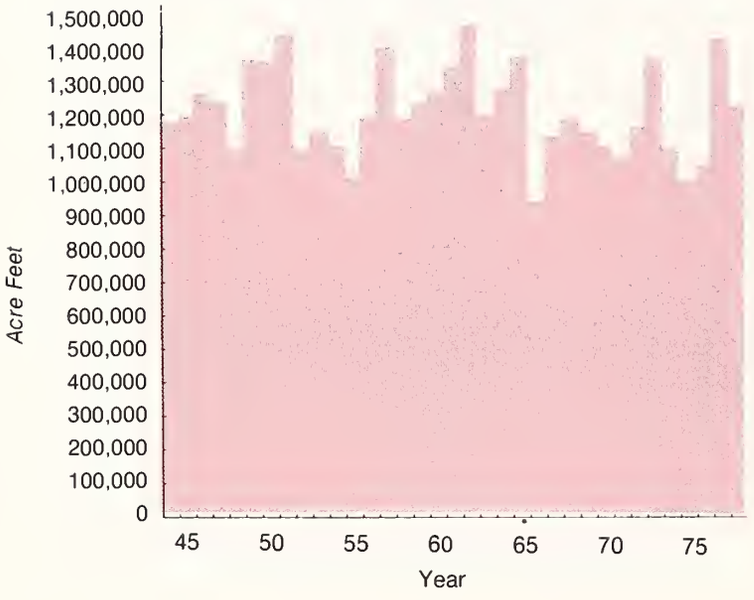


Figure 50
Annual Water Diversion
Sutherland Canal from North Platte River, Nebraska

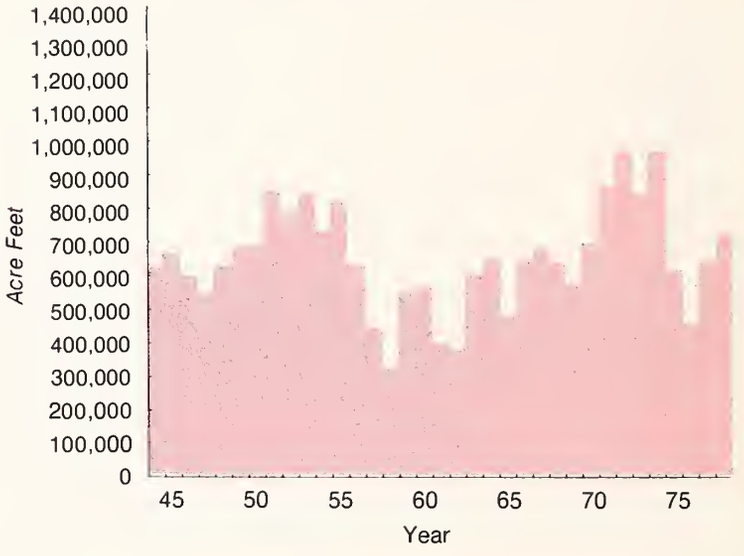


Figure 51
Annual Water Diversion
Sutherland Canal from South Platte River, Nebraska

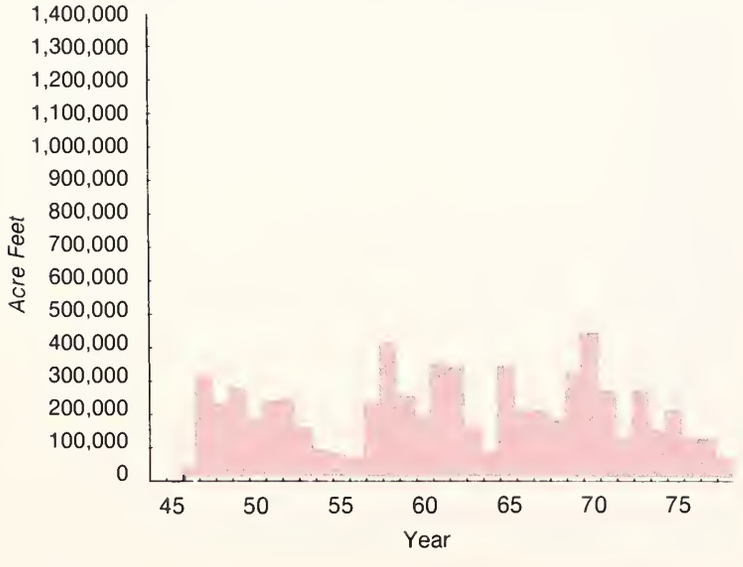


Figure 52
Annual Water Diversion
Interstate Canal from North Platte River, Wyoming-Nebraska
(Actual Annual Transfer was 90% of That Shown)

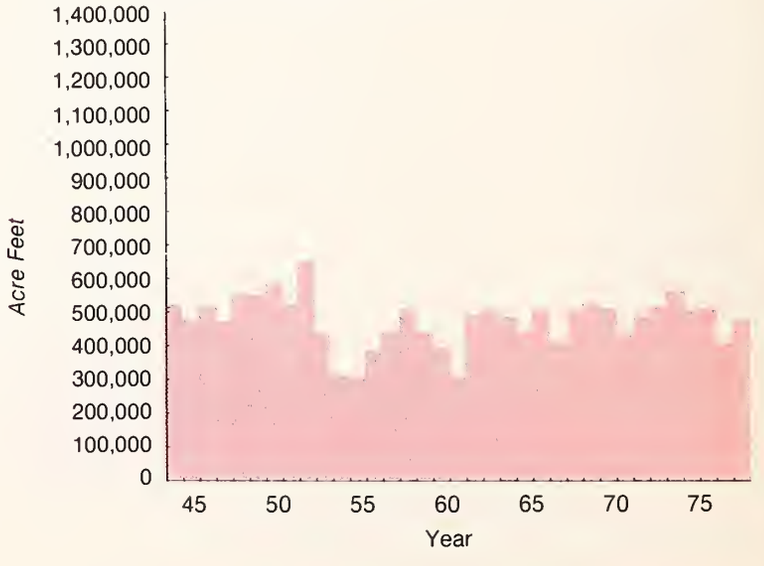


Figure 53
Annual Water Diversion
Mitchell Canal from North Platte River, Wyoming-Nebraska

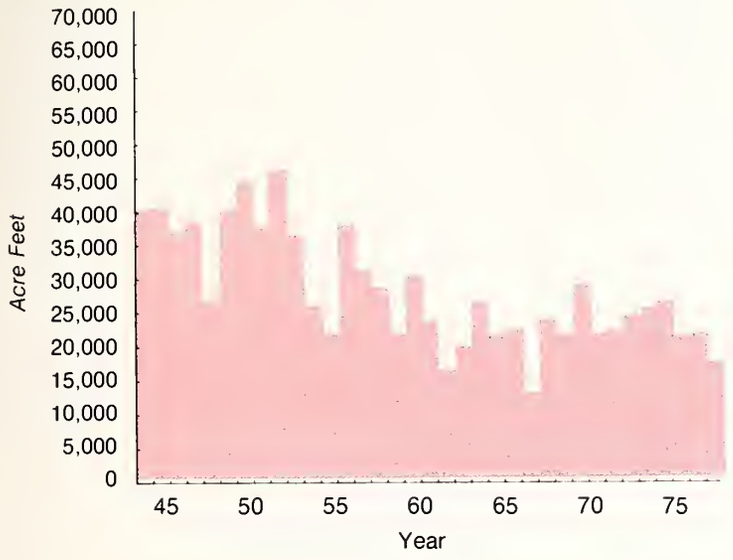
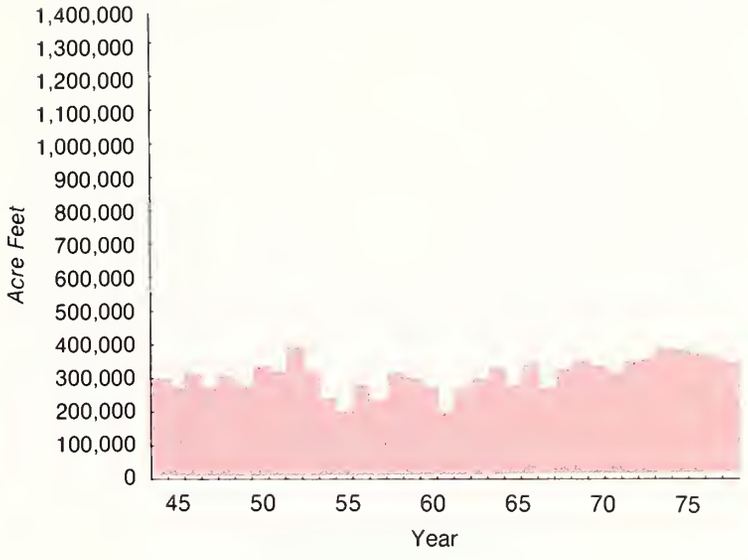


Figure 54
Annual Water Diversion
Fort Laramie Canal from North Platte River, Wyoming-Nebraska
(Actual Annual Transfer was 65% of That Shown)



In this subbasin there are four major reservoirs, Figure 38, Lake McConaughy, the reservoir behind Kingsley Dam, with a normal capacity of 1,948,000 acre-feet is the largest in the subbasin. Seminoe Reservoir with a normal capacity of 1,011,000, Pathfinder Reservoir with a normal capacity of 1,016,000 and Glendo Reservoir with a normal capacity of 523,500 form the major reservoirs in the North Platte system of reservoirs operated by the U.S. Bureau of Reclamation. Annual evaporation from McConaughy, Seminoe, Pathfinder and Glendo Reservoirs are shown in Figure 55 through Figure 58. Average annual evaporation from those four reservoirs totals about 174,700 acre-feet per year. Evaporation from all small reservoirs in the subbasin averages about 200,600 acre-feet annually.

Colorado has always been an "appropriation" doctrine state. Under this doctrine, unappropriated water of every natural stream is subject to appropriation, and priority of appropriation shall give the better right.

Responsibility for water administration and control in Colorado is divided between the State Engineer and the Judiciary. The State Engineer administers, distributes, and regulates the waters of the state. Water judges have exclusive jurisdiction in the determination of amounts and priorities on application for new water rights and conditional water rights, determination of rights with respect to proposed changes of water rights, plans for augmentation and biennial findings of due diligence.

The State Engineer is responsible for the issuance of a permit to construct a well. In order to issue a permit, he must determine that there is unappropriated water available and that the vested right of others will not be materially injured by the issuance of a permit.

In contrast, the State of Nebraska continues to provide recognition to riparian rights on lands patented prior to April 4, 1895. However, the appropriation doctrine is the primary doctrine for allocation of surface waters. The State of Nebraska is party to four interstate agreements and one U.S. Supreme Court decree within the Missouri River basin. These are the Kansas-Nebraska Big Blue River Compact, Republican River Compact, South Platte River Compact, Upper Niobrara River Compact and the Supreme Court decree on the North Platte River. The states of Colorado and Wyoming are party to the Laramie River Decree.

There is an interstate compact in force in this subbasin; that is, the South Platte River Compact between Colorado and Nebraska. Details of the provisions of the court decrees and compacts can be found in other documents.

In the Platte-Niobrara Subbasin, the major water user is irrigation. In 1978 irrigation accounted for 83 percent of the total water used, Figure 59.

In this subbasin, ground water is a major source of water. Irrigated acres using ground water increased from about 238,000 acres in 1944 to over 2,913,000 acres in 1978. The largest growth in irrigation using ground water occurred after 1960. Ground water is also an important source of supply for municipal, industrial and energy use within the subbasin. During the 1944 to 1978 period, irrigated acres using surface water sources increased by only 232,600 acres. Surface water depletions due to ground water pumpage for municipal, industrial and energy uses exceeded 87,000 acre-

Figure 55
Average Monthly Evaporation
Lake McConaughy
(Kingsley Reservoir)

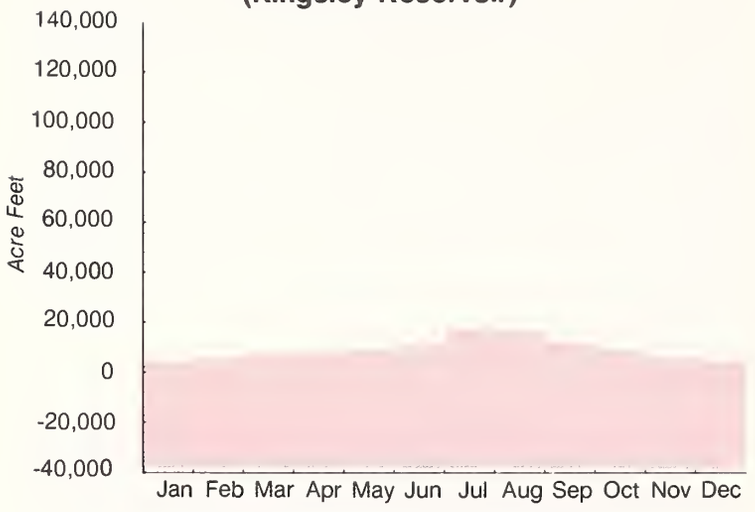


Figure 56
Average Monthly Evaporation
Seminoe Reservoir

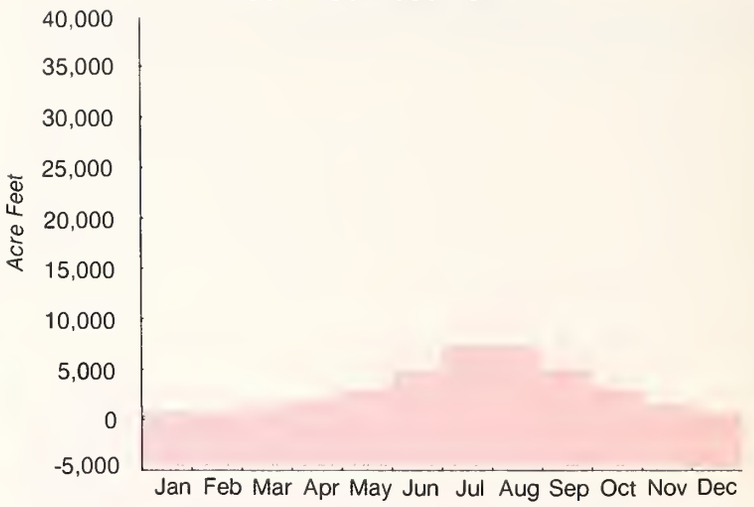


Figure 57
Average Monthly Evaporation
Pathfinder Reservoir

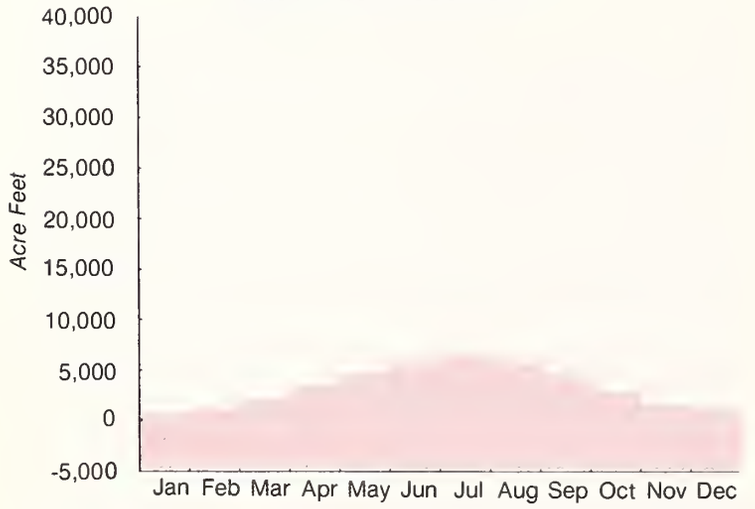


Figure 58
Average Monthly Evaporation
Glendo Reservoir

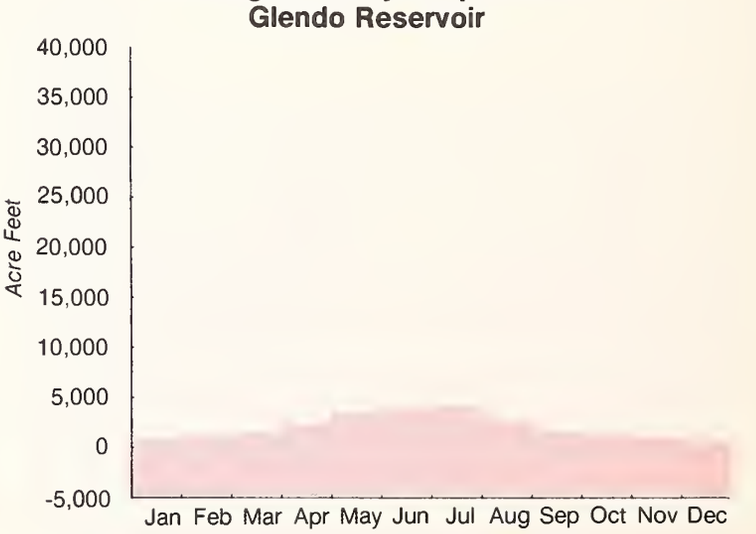


Figure 59
Platte-Niobrara Subbasin
Total Annual Historic Streamflow Depletion
by Type of Use
1944, 1960 and 1978

	Other Depletions - Percent of Total		
	1944	1960	1978
Small Reservoirs	3.3	3.0	3.7
Municipal, Industrial, Energy (Ground Water Pumpage)	1.0	1.4	1.6
Conservation Measures	0.4	0.8	1.0
Farm Ponds	0.5	1.2	1.4
Livestock	0.8	0.6	0.6
Municipal	1.3	1.9	3.0
Industrial	0.1	0.1	0.1
Energy	0.1	0.9	1.9
Rural Domestic	0.5	0.5	0.5
TOTAL	**8.0**	**10.4**	**13.8**

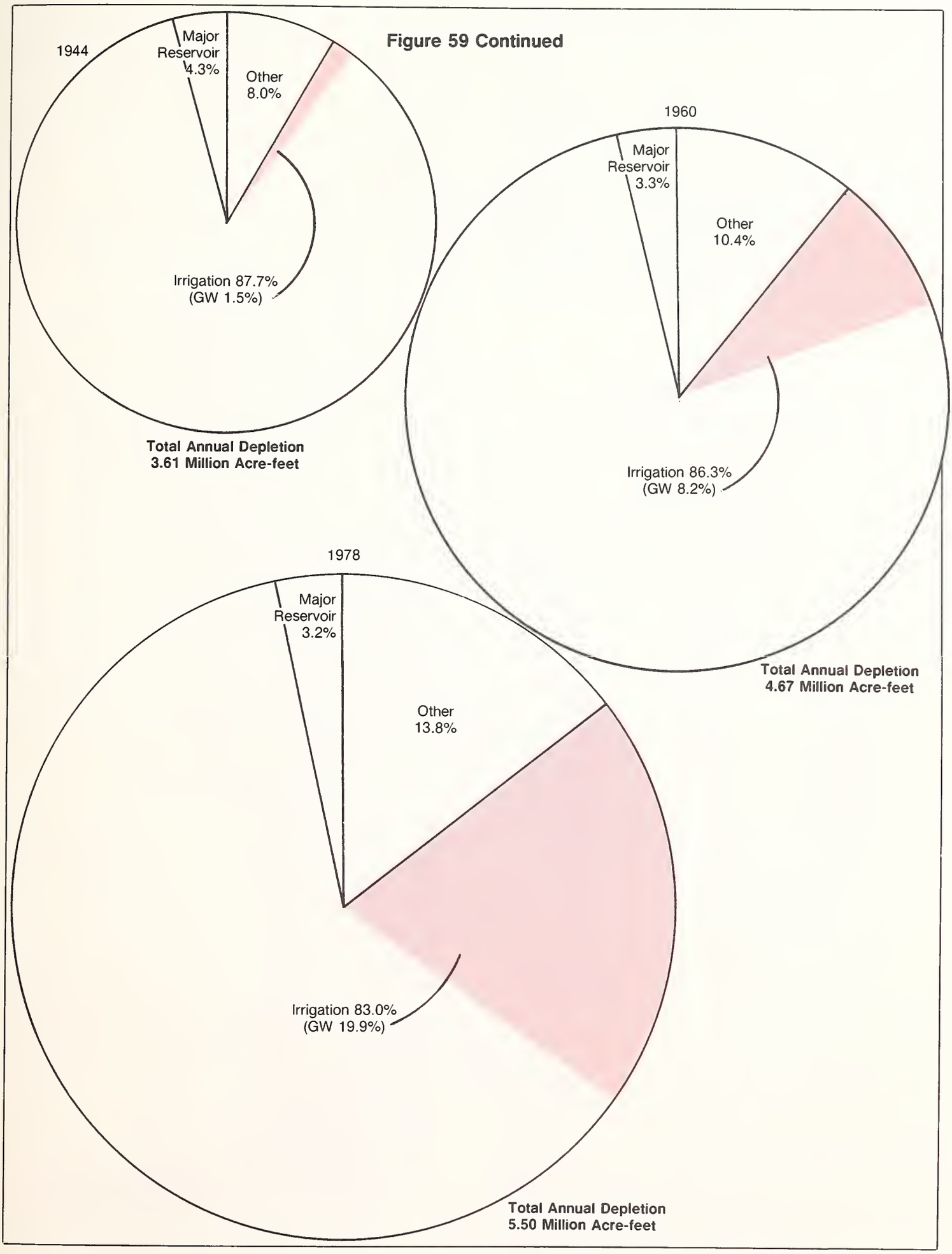


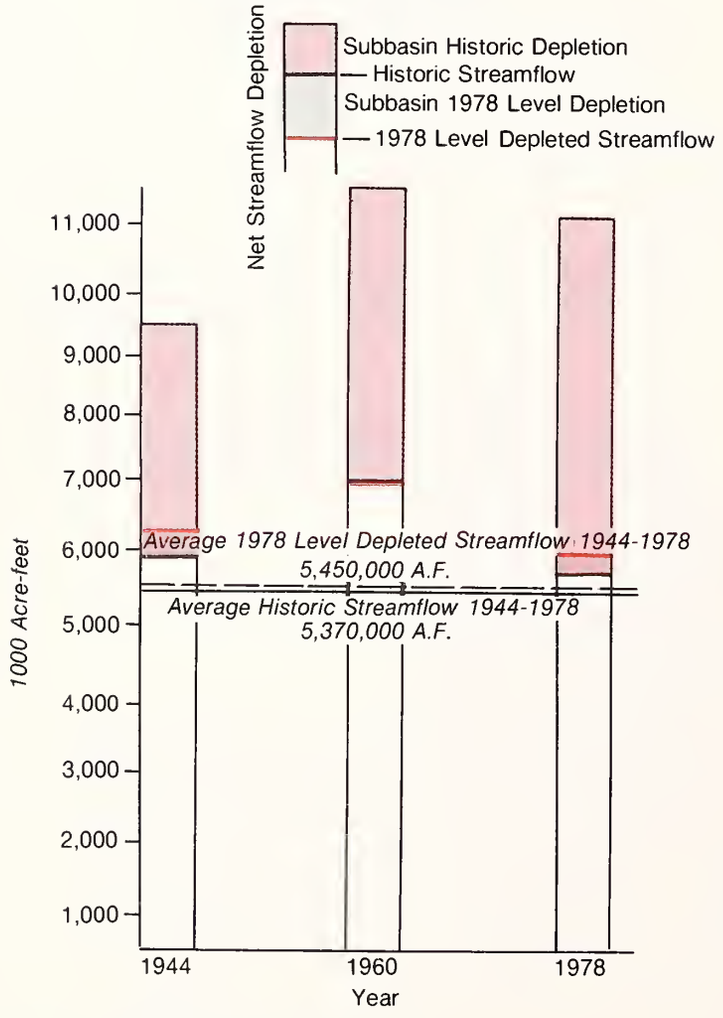
Figure 59 Continued
1944
Major Reservoir 4.3%
Other 8.0%
Irrigation 87.7% (GW 1.5%)
Total Annual Depletion 3.61 Million Acre-feet
1960
Major Reservoir 3.3%
Other 10.4%
Irrigation 86.3% (GW 8.2%)
Total Annual Depletion 4.67 Million Acre-feet
1978
Major Reservoir 3.2%
Other 13.8%
Irrigation 83.0% (GW 19.9%)
Total Annual Depletion 5.50 Million Acre-feet

feet in 1978. At the same time surface water depletion due to ground water pumpage for irrigation exceeded 1 million acre-feet.

From 1944 to 1978 total annual surface water depletions increased by about 1.89 million acre-feet. The majority of that was a result of increased irrigation within the subbasin.

A graph of selected years of the 1978 level depleted streamflow is shown on Figure 60. On the average, based on the 1944 to 1978 adjusted streamflow and subject to state water rights, interstate compacts, and instreamflow requirements, 5,450,000 acre-feet are available for all nonconsumptive and new consumptive uses above this stream gage.

Figure 60
Platte-Niobrara Subbasin
1978 Depleted Streamflow
Platte River at Louisville, Nebraska, and Niobrara River near Spencer, Nebraska
1944, 1960 and 1978



Middle Missouri Subbasin

The Middle Missouri Subbasin covers 24,602 square miles in the east central part of the Missouri River basin, Figure 61. Several small streams are direct tributaries to the Missouri in this subbasin. Principal among these are the Little Sioux, Nishnabotna, and the Nemaha Rivers. The topography is generally rolling with a wide flood plain along the Missouri bounded with sharp bluffs which often have several hundred feet of relief. The elevations vary from about 1,220 in the north to about 750 feet in the vicinity of Kansas City, Missouri. The majority of the subbasin is located in the States of Nebraska and Iowa, with smaller parts in Minnesota, Kansas, and Missouri.

Most lands are developed for agricultural or industrial purposes. However, about 5 percent of the subbasin is occupied by forested lands. Those lands include eastern dedicuous forests and flood plain forests.

Development of the ground water resources in this subbasin has been limited largely due to the high rainfall received over the basin.

Flows in the Missouri River in this reach are controlled by the six main stem reservoirs located upstream of the subbasin. The surface water outflow point selected for this subbasin is the USGS gage number 06893000 on the Missouri River at Kansas City, Missouri. The drainage area above that point is approximately 485,200 square miles. For the 1944 to 1978 period of record, the average recorded streamflow at that point was about 52,314 c.f.s. or 37.9 million acre-feet annually.

One water transfer occurs in this subbasin. The Monona-Harrison Ditch diverts water from the Little Sioux River around the City of Turin to the Missouri River. Wide annual variations occur, with annual water transfers varying from 50,000 acre-feet to 2.4 million acre-feet over the 35-year period, Figure 62.

Evaporation from all small reservoirs in the subbasin averages about 1,000 acre-feet annually.

Figure 62
Annual Water Diversion
Monona-Harrison Ditch near Turin, Iowa

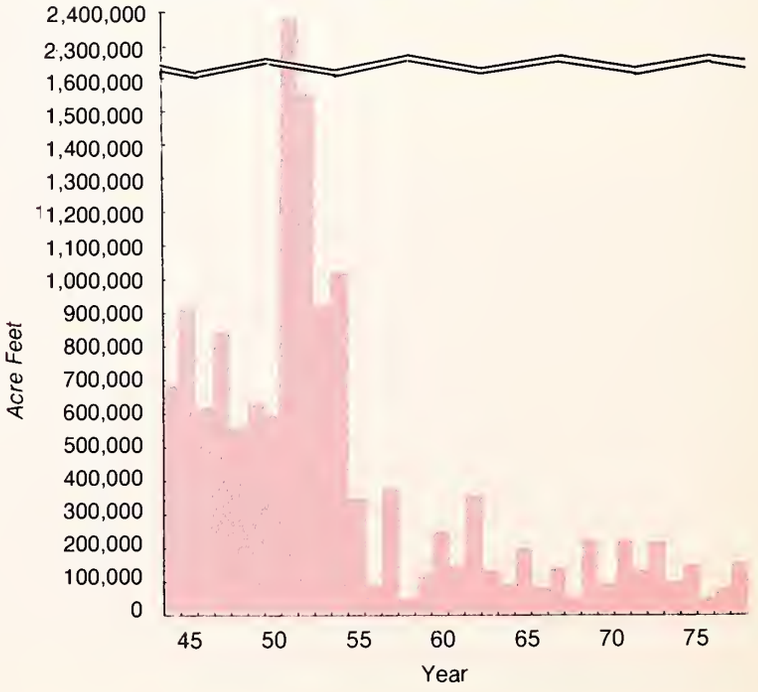


Figure 61
Middle Missouri Subbasin

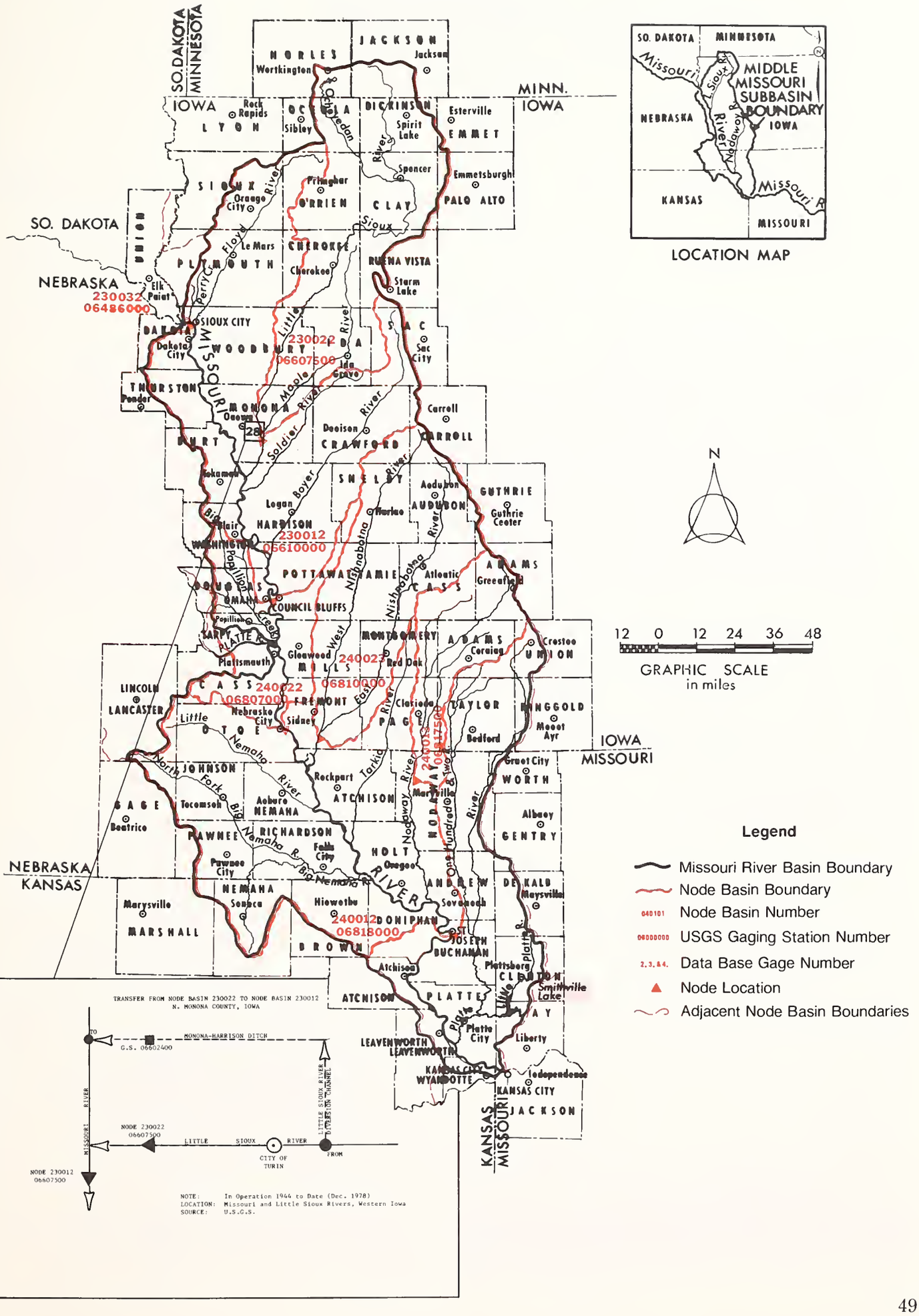
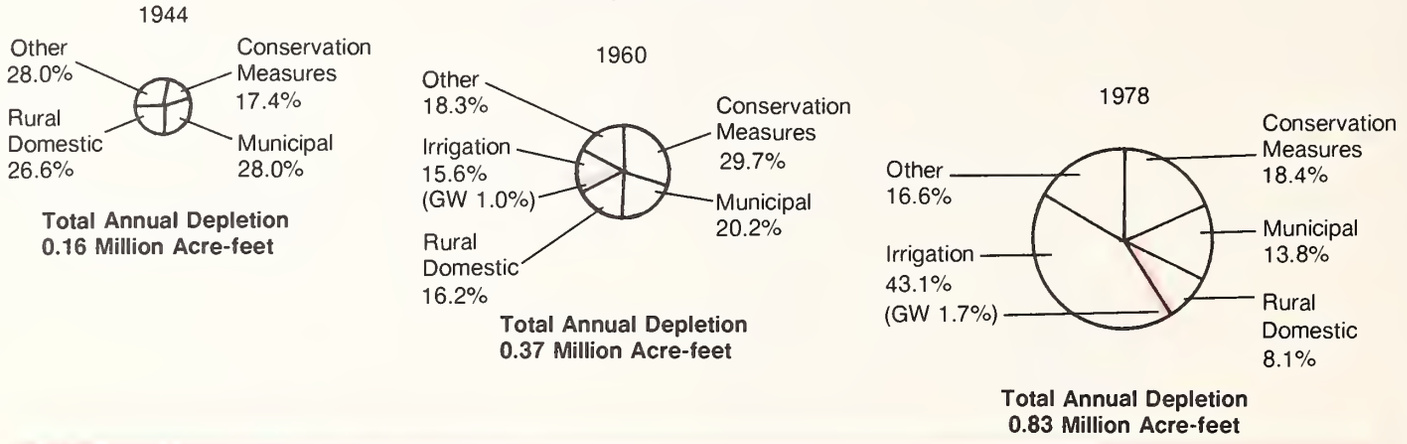


Figure 63
Middle Missouri Subbasin
Total Annual Historic Streamflow Streamflow
by Type of Use
1944, 1960 and 1978



Other Depletions - Percent of Total

	1944	1960	1978
Small Reservoirs	0.2	0.1	0.1
Farm Ponds	7.5	9.2	5.8
Livestock	12.1	5.7	2.6
Industrial	6.8	2.2	0.9
Energy	1.4	1.1	7.2
TOTAL	**28.0**	**18.3**	**16.6**

Classified as a riparion water law state, Iowa utilized a permit system to allocate water. Applications for permission to divert, pump or store water from any water course for any purpose other than a non-regulated use must be submitted to the Iowa Natural Resources Council. Statutory guidelines specify water uses which require permits.

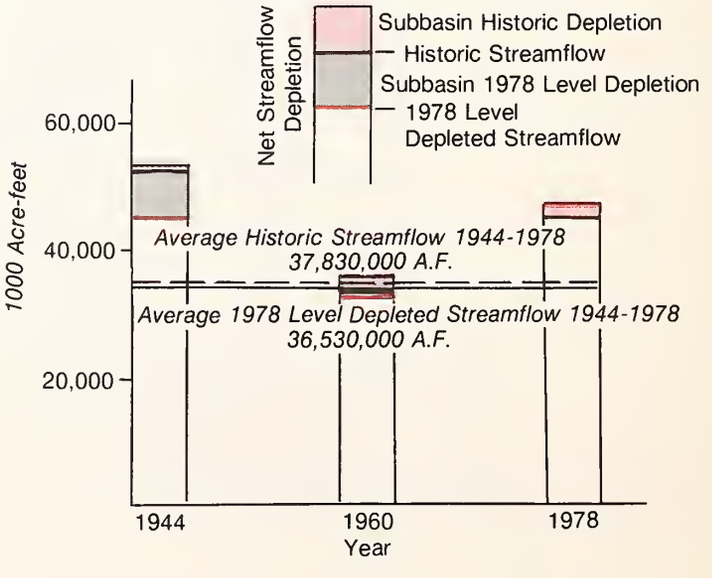
In 1978 the four major water users, in this subbasin were: irrigation, rural domestic, municipal and land conservation measures, Figure 63.

Irrigation increased from less than 100 acres in 1944 to over 297,000 in 1978. The area of land treated by land conservation measures has also increased and in 1978 totaled almost 5.6 million acres. In 1978 depletions for conservation measures were estimated to total almost 153,000 acre-feet annually. The population of this area is primarily urban, with a 1978 urban population of 975,300, or 63% of the total population. Depletions for municipal water use in 1978 were in excess of 114,600 acre-feet, or almost 14 percent of the total for the subbasin.

Total depletions in this subbasin have increased from 160,000 acre-feet in 1944 to about 830,000 acre-feet in 1978. The majority of that increase is due to increased irrigation in the subbasin.

A graph of selected years of the 1978 level depleted streamflow is shown on Figure 64. On the average, based on the 1944 to 1978 adjusted streamflow and subject to state water rights, interstate compacts, and instreamflow requirements, 36,530,000 acre-feet are available for all non-consumptive and new consumptive uses above this stream gage.

Figure 64
Middle Missouri Subbasin
1978 Level Depleted Streamflow
Missouri River at Kansas City, Missouri
1944, 1960 and 1978



Kansas River Subbasin

The Kansas River Subbasin covers 60,744 square miles along the southern edge of the Missouri River basin, Figure 65 (page 53). Principal tributaries are the Republican, Big Blue, Solomon, and Smoky Hill Rivers. The topography is gently rolling with scattered buttes in the western area. Elevations range from about 6,000 feet in Colorado to about 750 feet near Kansas City. The majority of the subbasin is located in Kansas and Nebraska. A smaller part is located in eastern Colorado.

Agricultural use dominates the basin's land resources. Major dryland crops include small grains.

Ground water is abundant along stream alluvial aquifers. In addition, the High Plains Aquifer underlies the western third of the subbasin. That aquifer provides an important source of water for irrigation and other purposes.

In this subbasin, surface water is highly variable. Because of the dry continental climate, available runoff is subject to severe seasonable variations as well as variations from year to year. The surface water outflow point selected for this subbasin is the USGS gage number 06892350 located on the Kansas River at Desoto, Kansas. The drainage area above that point is 59,756 square miles. For the 1944 to 1978 period of record, the average recorded streamflow at that point was 8,166 c.f.s., or 5.9 million acre-feet annually.

Two projects transfer water in this subbasin. The first is the Pioneer-Haigler Canal that transfers water from the north fork of the Republican River across the Nebraska-Colorado stateline. Water deliveries from this project, in operation since the late 40's, have ranged from about 6,000 to 19,000 acre-feet annually, Figure 66. The second water transfer project is the Courtland Canal which transfers water from the Republican River in Nebraska across the Nebraska-Kansas stateline to White Rock Creek in Kansas. Water deliveries from this project, in operation since the early 50's, have ranged from about 1,000 to over 120,000 acre-feet annually, Figure 67.

Six major reservoirs are located in this subbasin, Figure 65. Glen Elder, with a normal capacity of 241,500 acre-feet is operated by the Bureau of Reclamation. The others: Milford, Perry, Tuttle Creek, Wilson and Harlan County are operated by the Corps of Engineers. Normal capacities for these five reservoirs are: 407,000, 243,000, 413,000, 245,000 and 342,000 acre-feet, respectively. Total average annual evaporation for the six reservoirs is about 290,800 acre-feet. Average monthly evaporation for the six reservoirs are shown in Figure 68 through Figure 73. Evaporation from all small reservoirs in the subbasin averages about 29,000 acre-feet annually.

Subject to vested rights, water in the State of Kansas may be appropriated for beneficial uses. As is the case with other prior appropriation water law states,

Figure 66
Annual Water Diversion
Pioneer-Haigler Canal from the Republican River (Parshall Flume), Kansas
(Actual Annual Transfer was 68% of That Shown Above)

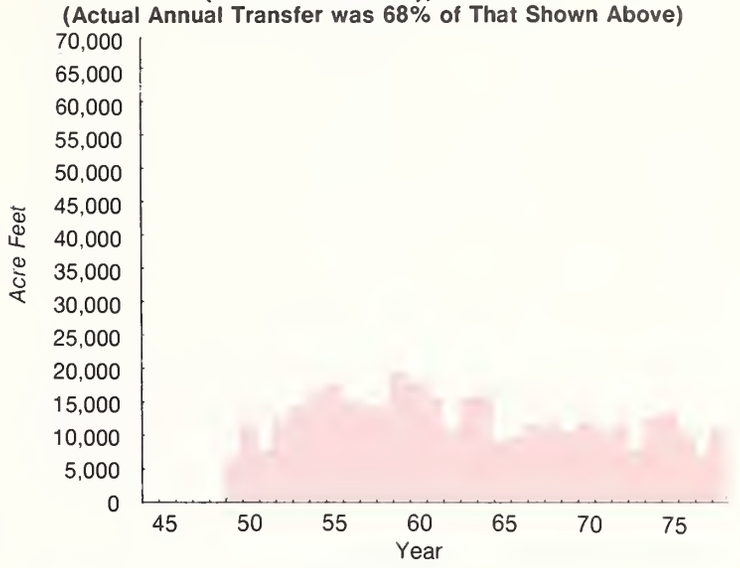


Figure 67
Annual Water Diversion
Courtland Canal from the Republican River, Kansas
(Actual Annual Transfer was 84% of That Shown)

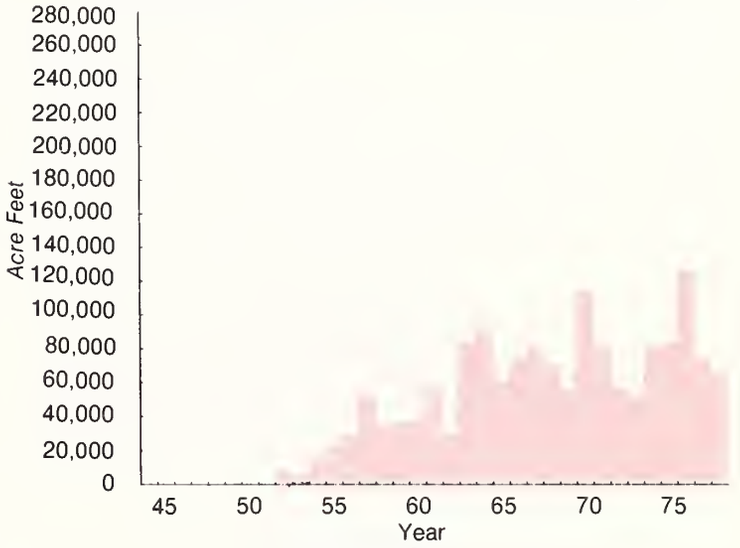


Figure 68
Average Monthly Evaporation
Harlan County Reservoir

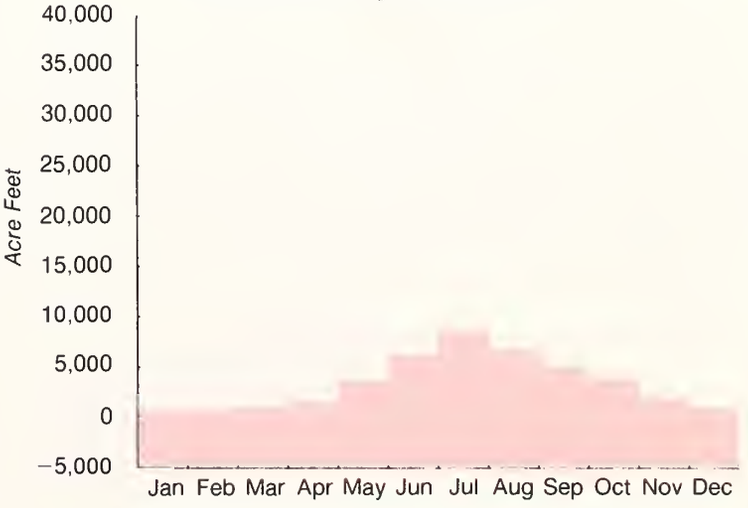


Figure 69
Average Monthly Evaporation
Glen Elder Reservoir

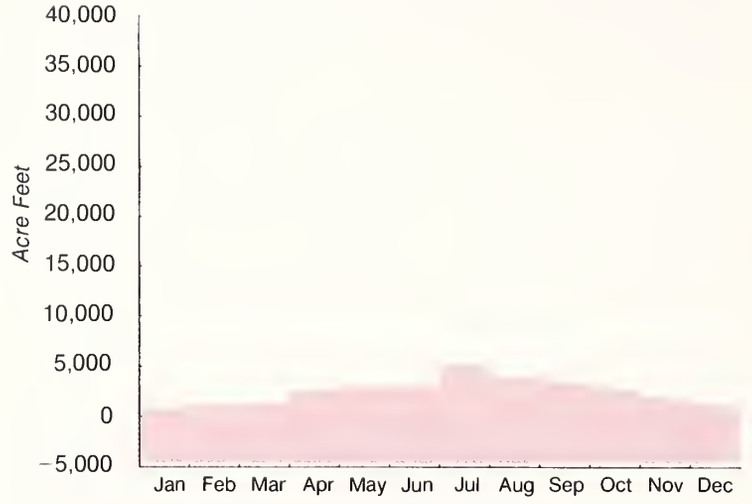


Figure 70
Average Monthly Evaporation
Tuttle Reservoir

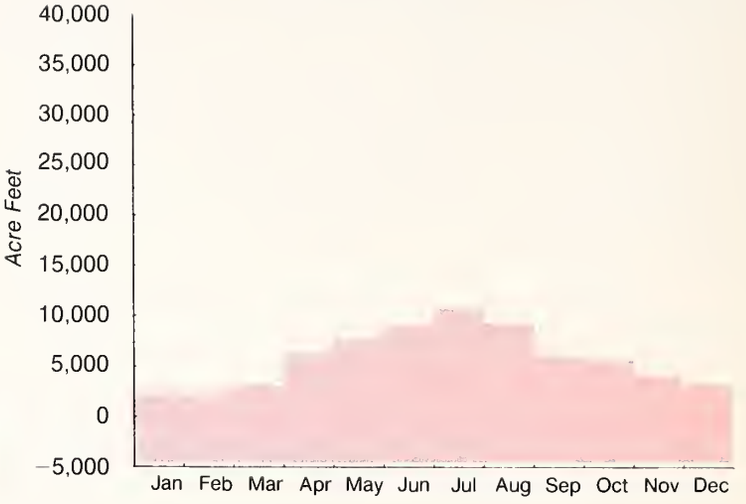


Figure 71
Average Monthly Evaporation
Perry Reservoir

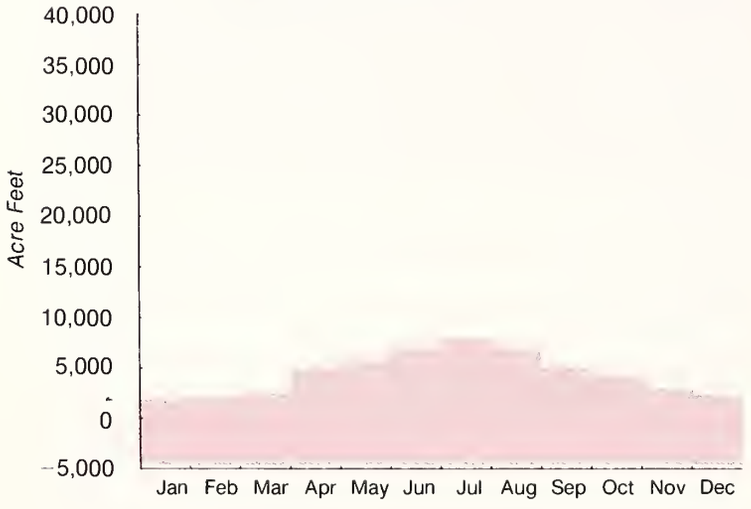


Figure 72
Average Monthly Evaporation
Wilson Reservoir

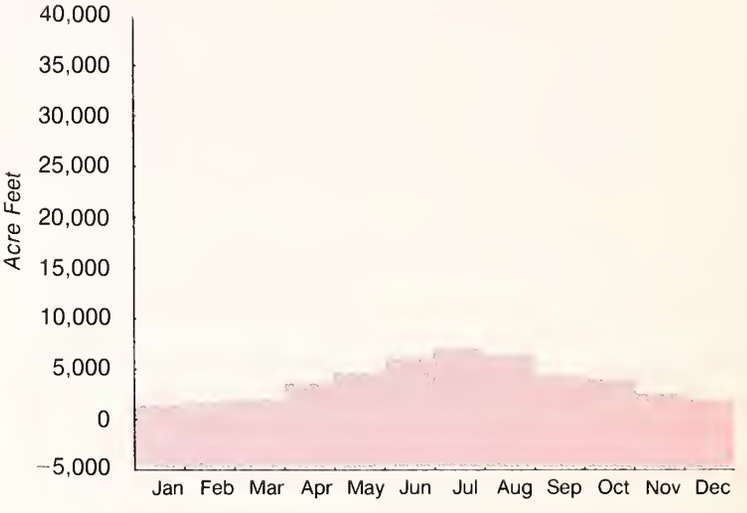
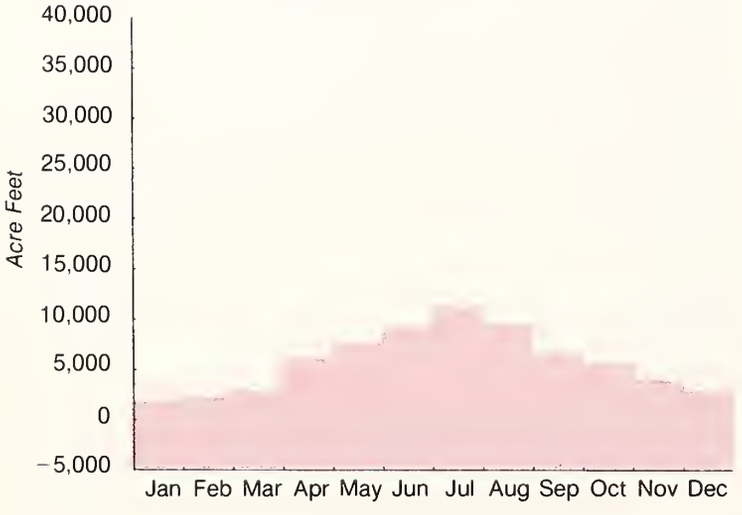


Figure 73
Average Monthly Evaporation
Milford Reservoir



the first in time is the first in right. Two interstate accords affect water allocation in Kansas. These are the Republican River Compact involving the States of Colorado, Nebraska and Kansas, and the Kansas-Nebraska Big Blue River Compact.

In 1978 in the Kansas River Subbasin, the three major water users were: irrigation, evaporation from major reservoirs, and farm ponds, Figure 74. In the Kansas Subbasin ground water is an important source of supply. By 1978 irrigated acres using a ground water source totaled in excess of 3.2 million acres. Surface water depletions due to ground water pumpage were estimated at almost 360,000 acre-feet annually for 1978. Unlike the Platte Subbasin, in the Kansas Subbasin the transmissivity values are relatively low adjacent to the river, thus causing the stream depletion factor bands to be very narrow bands along the river.

Figure 65
Kansas Subbasin

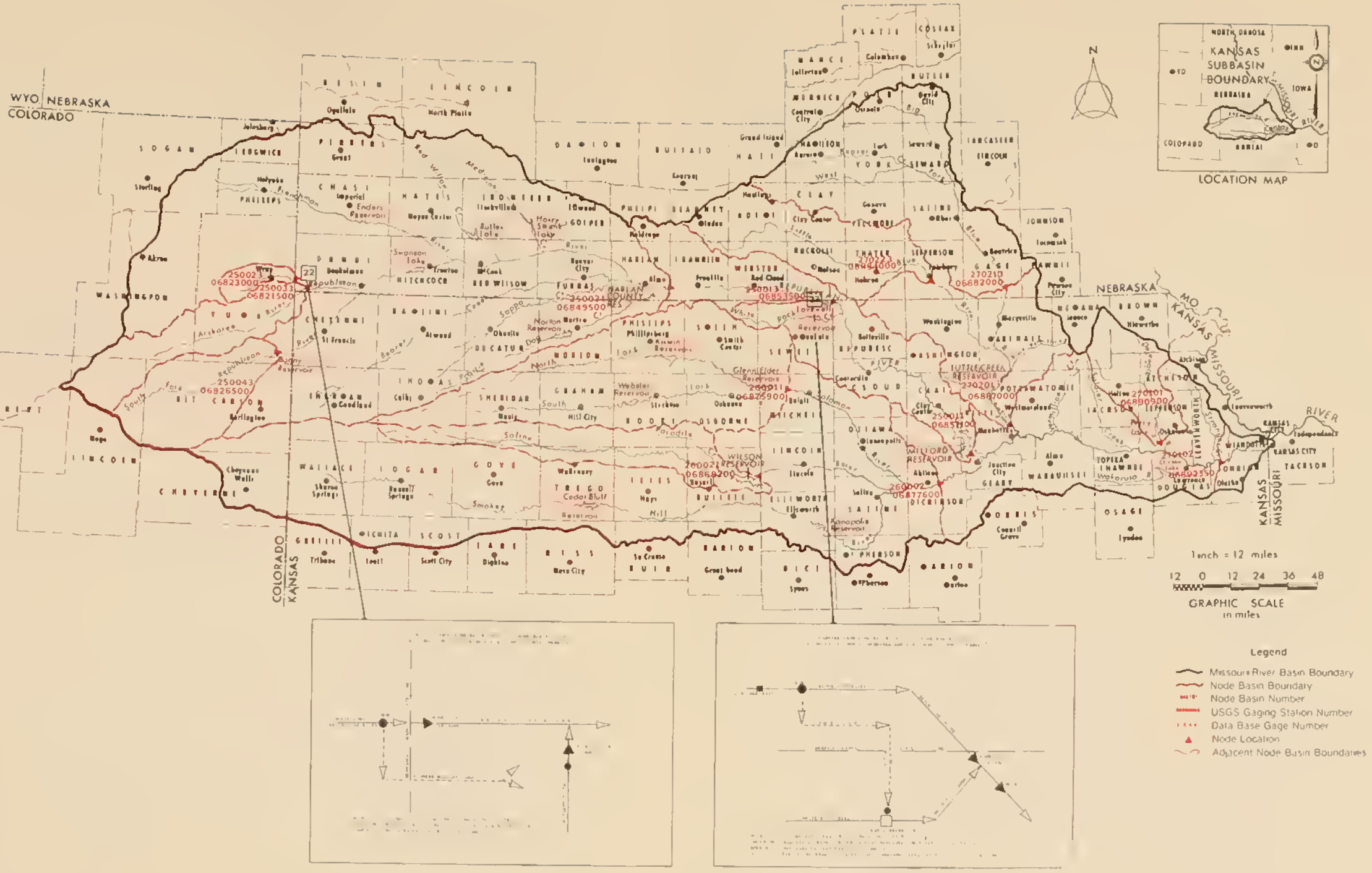
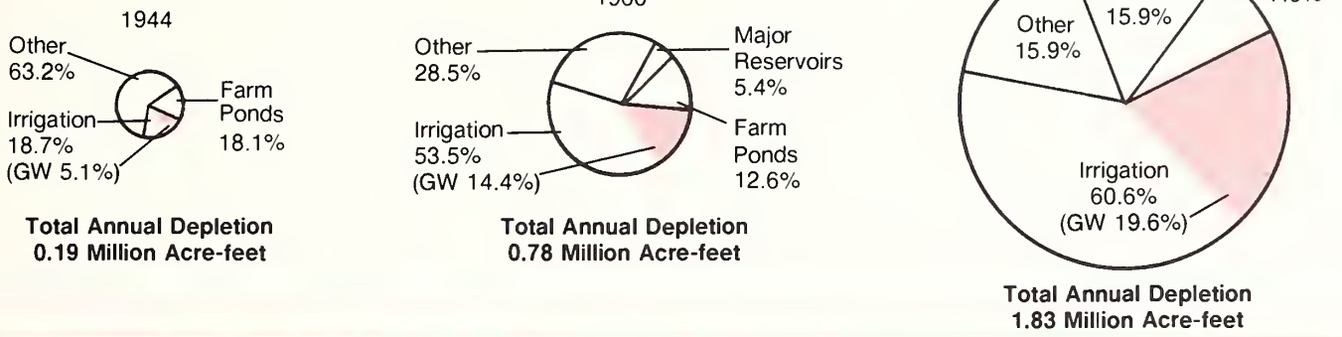


Figure 74
Kansas Subbasin
Total Annual Historic Streamflow Depletion
by Type of Use
1944, 1960 and 1978



	Other Depletions - Percent of Total		
	1944	1960	1978
Small Reservoirs	1.7	3.2	1.6
Municipal, Industrial, Energy (Ground Water Pumpage)	6.3	2.9	2.5
Conservation Measures	14.3	12.3	7.2
Livestock	10.6	2.3	1.2
Municipal	2.2	1.2	0.9
Industrial	0.7	0.2	0.1
Energy	12.5	2.7	0.2
Rural Domestic	14.9	3.7	2.2
TOTAL	**63.2**	**28.5**	**15.9**

As a result, the majority of irrigated acres using a ground water source is located outside of the 15,000 day band and therefore had little impact on streamflow depletion. In addition, ground water pumpage for municipal, industrial and energy purposes depleted streamflow by an additional 46,300 acre-feet in 1978.

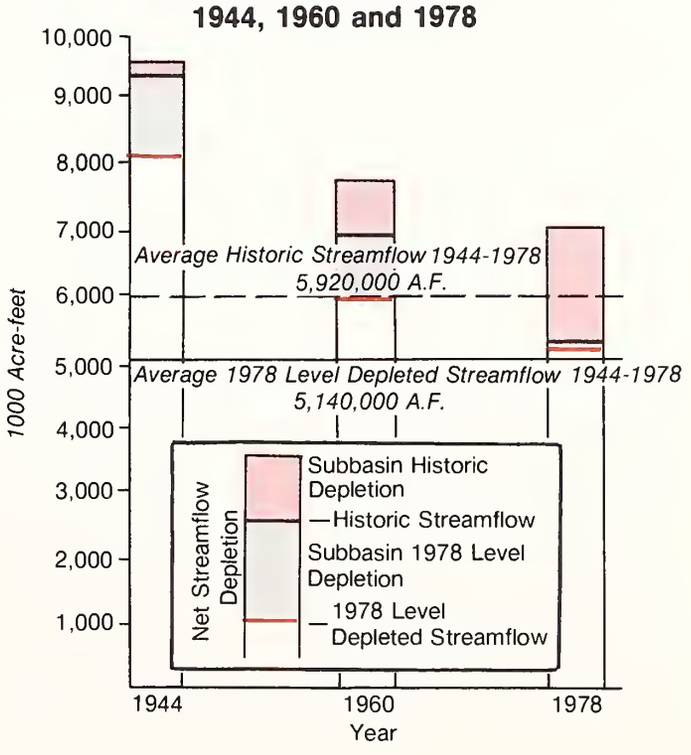
Irrigation has increased rapidly in the subbasin and totaled in excess of 3.6 million acres in 1978 from a 1944 level of 72,500 acres.

Conservation measures are also an important water depletor in the subbasin. In 1978 an estimated 12.8 million acres were under some form of land conservation treatment. Farm ponds in 1978, depleted almost 140,000 acre-feet annually.

From 1944 to 1978, total annual surface water depletions increased by about 1.64 million acre-feet. The majority of that is a result of increased irrigation within the subbasin.

A graph of selected years of the 1978 level depleted streamflow is shown on Figure 75. On the average, based on the 1944 to 1978 adjusted streamflow and subject to state water rights, interstate compacts and instreamflow requirements, 5,140,000 acre-feet are available for all non-consumptive and new consumptive uses above this stream gage.

Figure 75
Kansas Subbasin
1978 Level Depleted Streamflow
Kansas River at Desota, Kansas
1944, 1960 and 1978



Lower Missouri Subbasin

The Lower Missouri Subbasin covers 39,673 square miles in the extreme southeastern part of the Missouri River basin, Figure 76. Principal tributaries from the north are the Grand and Chariton Rivers. From the south the Osage and Gasconade Rivers are the principal tributaries. The topography is rolling in the northern part of the subbasin with elevations ranging to 1,450 feet. South of the Missouri River are the Ozark Foothills and the Flint Hills of east central Kansas.

The majority of the subbasin lies in Missouri, with small parts extending into Kansas and Iowa. The Missouri's confluence with the Mississippi River is located near St. Louis, Missouri.

Agricultural ecosystems dominate the land cover. However, considerable areas of oak and hickory forest exist in the Ozark Plateau. In addition, flood plain forests are found along major streams.

Ground water resources are an important source of water in this subbasin, but are limited primarily to domestic uses.

Mean annual precipitation is relatively high ranging from 32 inches in Iowa to 42 inches in south central Missouri.The surface water outflow point for this subbasin is the USGS gage 06934500 located on the Missouri River at Hermann, Missouri. The drainage area above that point is approximately 524,200 square miles. For the 1944 to 1978 period of record, the average recorded streamflow at that point was about 78,950 c.f.s. or 57.2 million acre-feet annually.

One of two exports of water from the Missouri River occurs in this subbasin. A pipeline diverts water from the Little Sac River to the City of Springfield, Missouri in the Arkansas River Basin. Exports, which first occurred in 1960, have increased from about 3,500 to over 17,000 acre-feet annually, Figure 77.

In this subbasin there are five major reservoirs, Figure 76. Harry S. Truman Reservoir was closed after 1978 and therefore did not impact the study, although for purposes of looking at future streamflow impacts, using the QUERY Program which is described later, the operation of the reservoir is included. Of the other three major reservoirs, Osage Dam, a private development of the Union Electric Company is the largest with a normal capacity of 2,020,000 acre-feet. Stockton Dam and Pomme De Terre Dam with normal capacities of 892,000 and 243,000 acre-feet, respectively, are both operated by the Corps of Engineers. As shown in Figure 78 through Figure 80, the average annual evaporation for these three reservoirs totals about 206,200 acre-feet annually. For purposes of this study, evaporation from Rathbun Dam in Iowa was included with the small reservoirs.

Missouri is among the eighteen eastern states which do not regulate water use under a permit system.

Figure 77
Annual Water Export
Little Sac River to Springfield Water Supply, Missouri

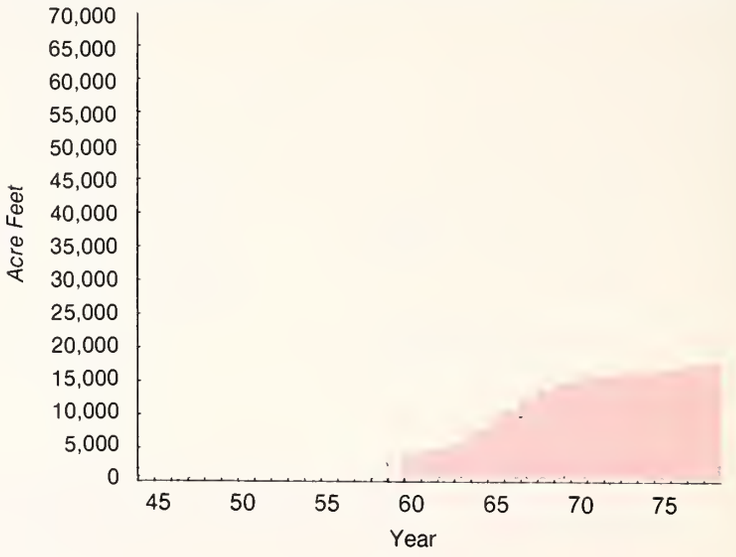


Figure 78
Average Monthly Evaporation
Lake of the Ozarks (Osage Dam)

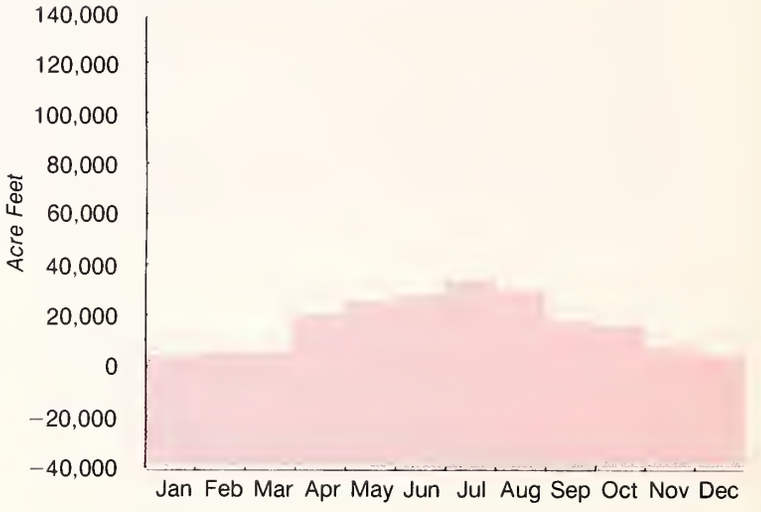
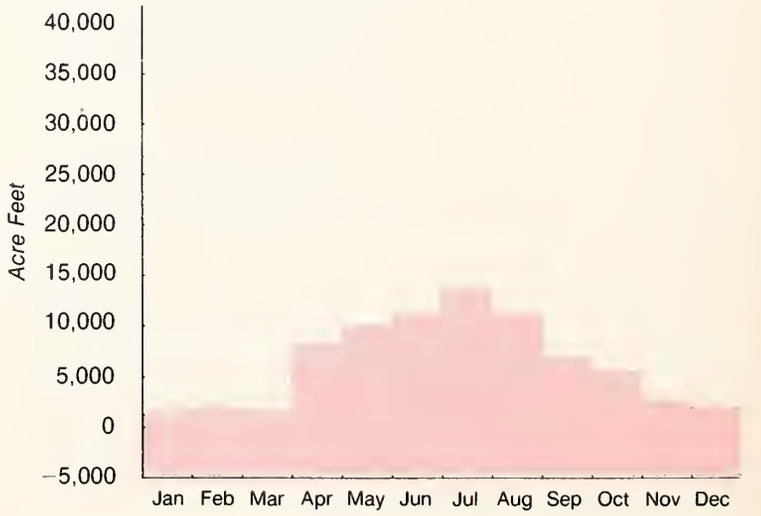


Figure 79
Average Monthly Evaporation
Stockton Lake (Stockton Reservoir)



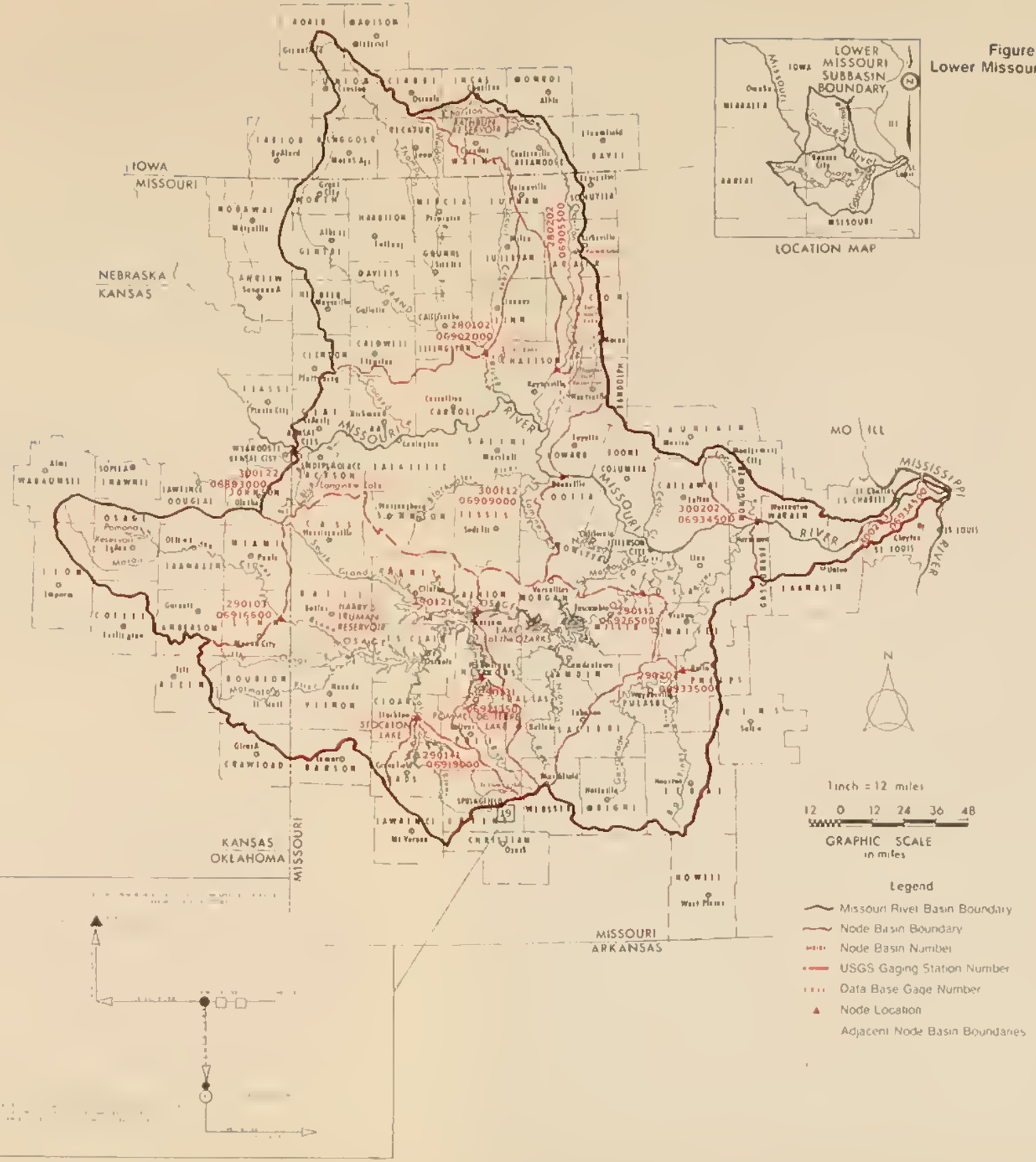
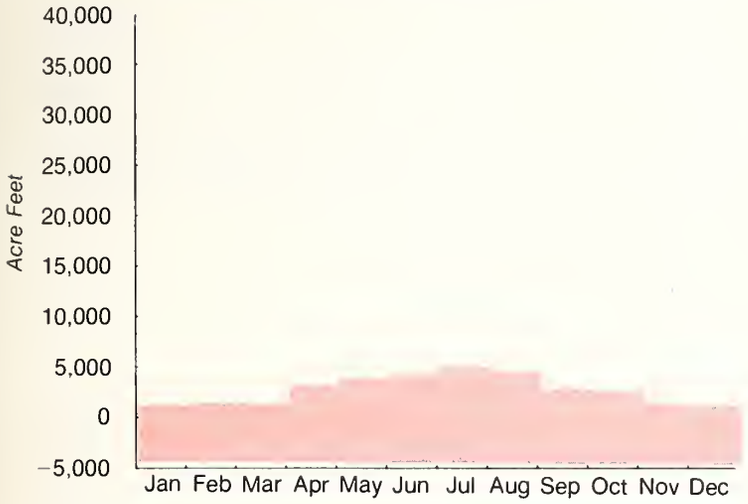


Figure 76
Lower Missouri Subbasin

Figure 80
Average Monthly Evaporation
Pomme de Terre Lake (Pomme de Terre Reservoir)



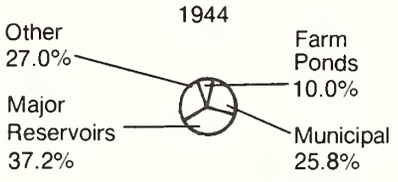
Within the state, the only applicable approach for allocation is the riparian doctrine; emphasis is, however, placed upon the reasonable use aspect of the doctrine.

In 1978, the four major water users in this subbasin were: municipal, farm ponds, evaporation from major reservoirs, and irrigation (Figure 81).

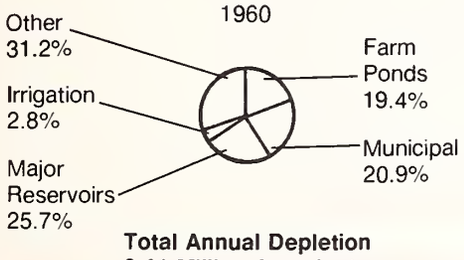
In 1944, irrigation was a minor user of water in this subbasin; however, by 1978, 11.2 percent of the total depletions was attributed to irrigation. By 1978 a total of almost 73,000 acres was under irrigation in the subbasin. With an urban population in 1978 in excess of 1.8 million, municipal water use was also an important depletor. By 1978, 139,600 acre-feet were being depleted annually for municipal use. Farm ponds in the subbasin also were an important depletor, with 1978 depletions estimated at 114,000 acre-feet.

From 1944 to 1978 total annual surface water depletions increased by about 450,000 acre-feet annually.

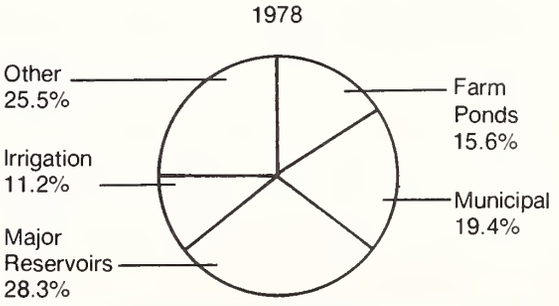
Figure 81
Lower Missouri Subbasin
Total Annual Historic Streamflow Depletion
by Type of Use
1944, 1960 and 1978



Total Annual Depletion
0.28 Million Acre-feet



Total Annual Depletion
0.41 Million Acre-feet

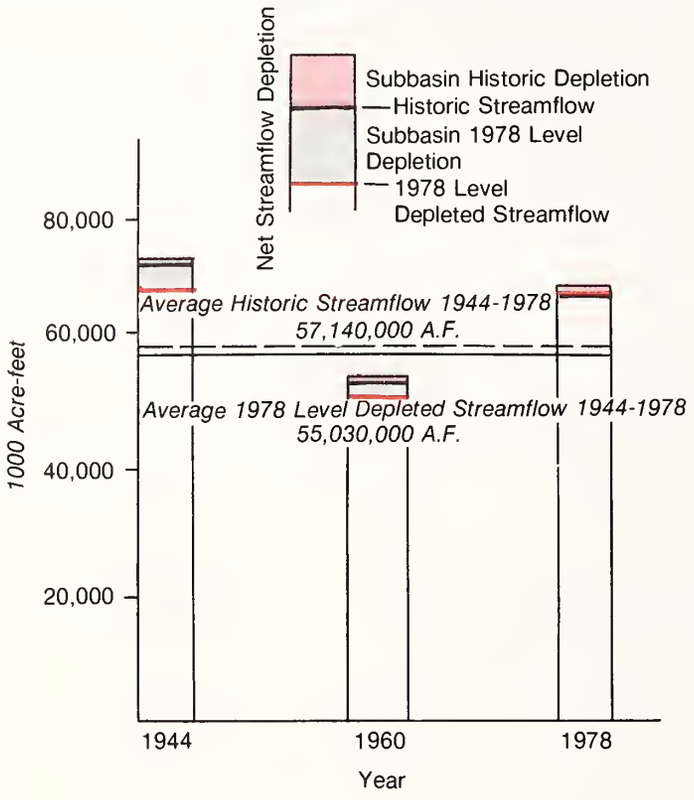


Total Annual Depletion
0.73 Million Acre-feet

Other Depletions - Percent of Total

	1944	1960	1978
Conservation Measures	3.3	8.6	7.8
Livestock	7.7	5.4	3.2
Industrial	2.3	1.9	1.2
Energy	5.9	8.1	7.6
Rural Domestic	7.8	7.2	5.7
TOTAL	**27.0**	**31.2**	**25.5**

Figure 82
Lower Missouri Subbasin
1978 Level Depleted Streamflow
Missouri River at the Mouth (Hermann Gage)
1944, 1960 and 1978



The majority of the increase was a result of increased irrigation in the subbasin and evaporation from major reservoirs constructed during that period.

A graph of selected years of the 1978 level depleted streamflow is shown on Figure 82. On the average, based on the 1944 to 1978 adjusted streamflow and subject to state water rights, interstate compacts and instreamflow requirements, 55,030,000 acre-feet are available for all non-consumptive and new consumptive uses above this stream gage.

THE MRB WATER ACCOUNTING SYSTEM

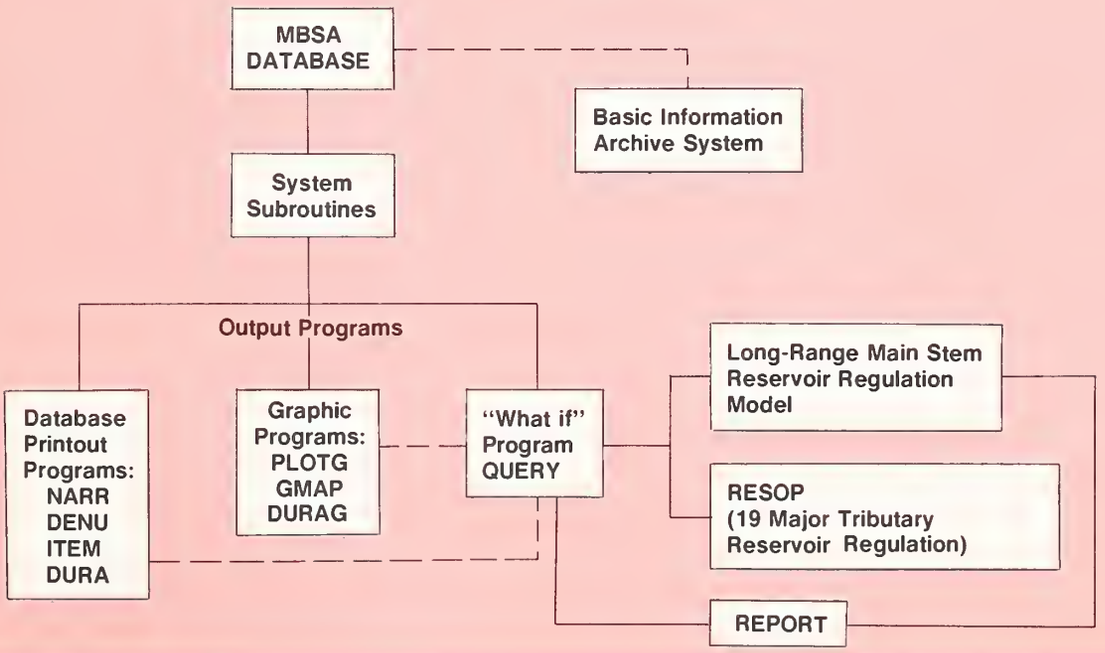
The MRB Water Accounting System is a series of interrelated computer programs which, when combined, form a means to store, access, and display the data. A diagram of the system is shown in Figure 83.

Basic Information Archive System

The Basic Information Archive System (BIAS) was developed to archive basic data, computer programs, computational procedures and other information not included in the database but used in developing values stored in the database. The purposes of developing BIAS are first, to preserve all information collected and techniques developed for the hydrology study in one central location for easier future access. The second purpose is to serve the states, federal agencies, and local interests as a major water resources information source for the Missouri River Basin. Third, the data collection methods, in most cases, used a worksheet approach which through the development of the BIAS could be refined toward computer-oriented techniques. Such techniques would improve the efficiency and facilitate the task of updating information in the database. Finally, the BIAS could be developed as an auxiliary system of the Water Accounting System's database to simplify the data transmitting processes.

Information stored in the BIAS is restricted to that which is not included in the Water Accounting System's database. The basic information gathered in the hydrology study covers parts of 10 states (473 counties and 93 node basins). Some of the data is provided by counties, others by node basins. Time interval of data

Figure 83
MRB Water Accounting System



varies and includes monthly, yearly, five-year, ten-year, and other intervals. The information stored was used in intermediate programs to generate data for the database.

The first step in development of the BIAS system was the inventory of available data and procedures developed by each work group during the hydrology study. To initiate the task, a preliminary list of data collected, methodologies, and programs was prepared and sent to the work group leaders for their review to fill in any missing information. After reviewing the inventory sheets, the BIAS storage system was to be designed. At that time, the magnitude of information that needed to be coded or keypunched was to be determined and estimates of the resources required to complete the system made. Based on the availability of funds and resources, uncoded data was to be stored in an appropriate format. Because of limited funding and manpower, the Management Group and MBSA Board of Directors at their August 25 and 26, 1982 meetings decided to microfilm and keep on file at the MBSA office as much of the information as possible. In that way, the information could be preserved so it may be reviewed and then the most pertinent information could be stored on the computer at some later time. A list of data contained in the BIAS is included in the technical paper of the System, Methods and Operation Work Group or is available through the office of the MBSA. That list shows how information is available either on computer tape, microfilm, xerox copy, or in a report.

Database Information

The Water Accounting System's database contains information that is stored in computer files arranged by node basin and by several categories of information. These categories include, by node basin, a yearly figure for the period 1944 through 1978 for the following depletor information:

- number of sites of surface water imports, exports, and node basin transfers,
- number of surface acres of small[a] reservoirs
- historic number of acres irrigated with ground water that deplete surface water
- historic number of municipal, industrial or energy sites using ground water that deplete surface water
- number of acres using surface water for full-service irrigation
- number of acres using surface water for partial-service irrigation
- number of acres using surface water for water-spreading irrigation
- number of acres of equivalent clearcut area in forest management
- number of acres of conservation measures
- number of surface acres of farm ponds
- number of head of livestock using surface water
- number of persons living in cities[b] using surface water
- number of industrial sites using surface water
- number of energy sites using surface water
- number of persons living in rural areas[c]

The historic depletion category includes, for the following, by node basin, a monthly figure in acre-feet for the period 1944 through 1978:

- surface water depletion due to small[d] reservoirs
- historic surface water depletion due to irrigation use of ground water
- historic surface water depletion due to other uses of ground water
- surface water depletion due to irrigation water use: full-service
- surface water depletion due to irrigation water use: partial-service
- surface water depletion due to irrigation water use: waterspreader
- surface water depletion due to forest management practices
- surface water depletion due to conservation measures
- surface water depletion due to farm ponds
- surface water depletion due to livestock water use
- surface water depletion due to municipal water use
- surface water depletion due to industrial water use
- surface water depletion due to energy water use
- surface water depletion due to rural domestic water use

Data on historic streamflow[e] including streamflows adjusted for imports and exports and inflows to major reservoirs are also stored in the database.

Another category includes, by node basin, narrative summaries of the following information:

- node station descriptive information
- overview of water law and process
- compacts and court decrees
- total water rights appropriated (some states)

This database information is available to users. Details on how the database information can be accessed are available in a separate report entitled "Users Guide — Missouri River Basin Water Accounting System," or by contacting the office of the Missouri Basin States Association.

System Subroutines

A series of subroutines was written to access the database. A brief description of those subroutines can be found in the technical paper of the System, Methods and Operation Work Group.

[a] Reservoirs larger than 40 acres of surface area at conservation storage, but smaller than 200,000 acre-feet of conservation storage.

[b] Cities with populations larger than 2,500 persons.
[c] Excluding cities with populations larger than 2,500 persons.
[d] Reservoirs larger than 40 acres or surface area at conservation storage, but smaller than 200,000 acre-feet of conservation storage.
[e] Most streamflow gaged, but some estimated.

Output Programs

A series of computer programs have been developed as a part of the Water Accounting System to access and list information stored in the database. The following are brief descriptions of those programs.

NARR — a program to print selected narrative files from the database to a remote job entry (RJE) terminal. A program that accesses the database and through a question and answer session, allows you to print on high speed terminal the various narrative files in the database.

DENU — a program to print selected depletion and depletor files from the database at an RJE terminal. The parameters may be selected from any of these files and printed in any desired order. An accumulated print is also given when upstream node basins are specified. The program enables you to access all of the depletors, historic depletions, 1978 level development depletions, and water depletion rates available in the database. There are 77 categories numbered between 1 and 79. By a question and answer session, information is available by any node basin for any of these 77 categories.

DURA — a program to print selected streamflow duration tables by node basin at an RJE terminal and a plot of the resulting curve at an interactive graphics terminal. A question and answer session asks which type streamflow you are interested in. There are four possibilities: 1) historic streamflow, 2) streamflow adjusted for imports and exports and node basin transfers, 3) 1978 level depleted streamflow, and 4) 1978 modified level depleted streamflow (available only with use of the QUERY Program). The program gives you the option of printing the table for the duration data on a high speed printer and/or drawing the graph of the duration with a pen plotter.

ITEM — a program that is used to summarize into a more digestible form the depletors and the depletions on an annual basis. Data is available by node basin, by subbasin, and by river reach as defined in the main stem reservoir model of the Corps of Engineers. An annual summary for all the depletors or depletions for 15 categories is printed across the page. It is a special printout and if it is a summary of the depletors or depletions, it is only available on a printer capable of printing 218 characters across the page. Also available through this program are annual depletion rates for the various categories.

QUERY — a program to determine the impacts to streamflow of modifying, either by addition or deletion, the depletions in one or more node basins. The program, again through questions and answers, allows the user to input into one of 14 categories modified depletions for any node basin. The program has the ability to take modified depletions for any or all of the 14 categories for any or all of the 93 node basins in the Missouri River Basin. These modified depletions are added onto the 1978 level depletions that are already resident in the database. They are consolidated toward the main stem and then as they are being consolidated, any of the 19 major tributary reservoirs that are intercepted are operated. The consolidation continues toward the main stem. When the main stem is reached, you have enough information to generate the input data set of the main stem model. The main stem model is then operated. The final output is a printout of the 1978 level depleted flow and modified depleted flow so you can compare the difference and magnitude of the impacts on streamflow of the run just made.

The actual physical layout of this program is in three parts. The front end is a question and answer session where the user tells the program in what node basins depletions are being modified. After that, there is no more user interaction. The program is set up so it consolidates all the depletions and moves toward the main stem using the tributary reservoir programs encountered on the way. After it has built the data set for the main stem program, it will exit the front end program. It then enters the main stem model and executes it. What physically happens is the first program builds an input data set that the main stem model picks up, uses, and then outputs another file that is used to access the third section of the program. The third section of the program puts the appropriate numbers into a database file and into files for the impacted nodes to give a final printout. Major subroutines of the QUERY program are the main stem reservoir regulation model and the operating programs for tributary reservoirs briefly described here.

Long-Range Main Stem Reservoir Regulation Model. A computer model has been developed by the Corps of Engineers, MRD Reservoir Control Center, to simulate the regulation of the six reservoirs comprising the Missouri River main stem system through an extended period of hydrologic record. Criteria used in the actual regulation of the reservoirs are incorporated into the model. This model has been provided to the Missouri Basin States Association to be utilized in the MRB Water Accounting System for determination of the main stem reservoir operation effects on streamflow depletion. The years 1944 through 1978 were selected as the study period. Details of the model are described in the Corps of Engineers MRD-RCC Technical Report F-81.

As developed, the Missouri River long-range main stem reservoir regulation computer program will not serve for day-to-day regulation of the reservoir system. Within the program, time periods are on a monthly basis or in some cases, one-quarter months. Actual regulation of the reservoir system uses daily forecasts, while the program developed allows for projections only with the assumption that near normal rainfall events will occur during the time periods under consideration. Forecasted monthly runoff from various reaches of the Missouri basin, monthly depletions, or monthly power demands can be used as program input. Output is on an average monthly basis.

Operating Programs for Tributary Reservoirs. The program RESOP was written to operate the other 19 major reservoirs within the Missouri River Basin having an active capacity of over 200,000 acre-feet. The main stem reservoirs operated by the Corps of Engineers use a separate simulation program and are not included in this description. The reservoirs included in this program are:

	Dam	Operating Agency	State
1.	Milford	Corps of Engineers	Kansas
2.	Perry	Corps of engineers	Kansas
3.	Tuttle Creek	Corps of Engineers	Kansas
4.	Wilson	Corps of Engineers	Kansas
5.	Glen Elder	Bureau of Reclamation	Kansas
6.	Kinglsey	Private	Nebraska
7.	Harlan County	Corps of Engineers	Nebraska
8.	Osage	Private	Missouri
9.	Stockton	Corps of Engineers	Missouri
10.	Pomme De Terre	Corps of Engineers	Missouri
11.	Harry S. Truman	Corps of Engineers	Missouri
12.	Canyon Ferry	Bureau of Reclamation	Montana
13.	Yellowtail	Bureau of Reclamation	Montana/Wyoming
14.	Tiber	Bureau of Reclamation	Montana
15.	Glendo	Bureau of Reclamation	Wyoming
16.	Pathfinder	Bureau of Reclamation	Wyoming
17.	Seminoe	Bureau of Reclamation	Wyoming
18.	Boysen	Bureau of Reclamation	Wyoming
19.	Buffalo Bill	Bureau of Reclamation	Montana

Graphics. A series of graphic output programs are available. Those programs provide the following by node basin:

1. Plots of any category of depletor and/or depletions or plots of one category vs. another category.
2. Trend analysis for any category of depletor or depletions for any time period 1944 through 1978.
3. Five-year moving average for any category of depletor or depletions for the period 1944 through 1978.
4. Duration flow curves of streamflow.
5. Node basin maps (under development at this time)

Details on the use of these programs are available in the MRB Water Accounting System Users Guide.

Use of the MRB Water Accounting System

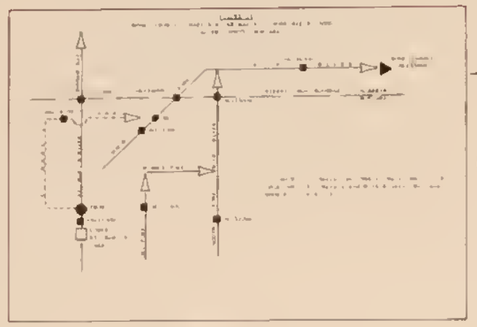
Water resource personnel, managers and decision-makers can use the Water Accounting System in three ways. First, users can make use of the extensive database covering the period 1944 through 1978 and selected graphic programs to evaluate trends in water use. Those trends could be used to make projections of future water use. Second, users can use the Water Accounting System to estimate how streamflow would be affected if specific additional uses are imposed upon the 1978 level of development. For example, a state may, in its water planning process, need to estimate potential impacts of new water developments that are streamflow depletors. Uses such as full service irrigation, municipal, energy, and in fact, 11 other categories of use can be addressed through the QUERY program of the Water Accounting System. Perhaps the most valuable use of this system is in addressing accumulative regional water resource impacts, because the system was designed to accumulate the effects of upstream depletions on downstream locations. In the Missouri River Basin, with the exception of Colorado and Minnesota, all states are in the position to one degree or another of being a downstream state, i.e., water developments in one state directly impact the streamflows in another state. Therefore, there is a great deal of interest between states on planned developments in upstream states.

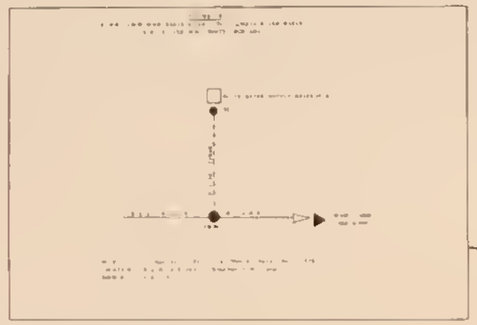
The "how-to's" of using the QUERY program, as well as the other output programs, are spelled out in detail in the Users Guide for the MRB Water Accounting System.

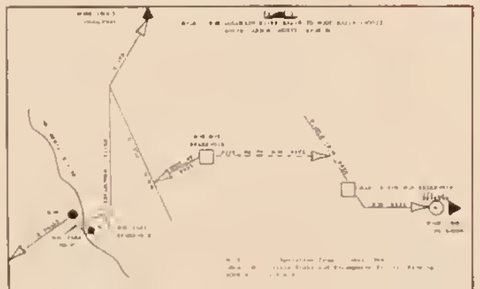
The third means of using the Water Accounting System is use of the data that makes up the database for use in studies being conducted. As listed earlier, included in that database are statistics including: population, the number of irrigated acres, the number of livestock, the number of acres of land conservation measures and other categories of water users. Associated with those statistics are estimated depletions to streamflow that are a result of water use for irrigation, urban population or other categories that correspond to the above user statistics. In addition, the database contains narrative information that describes the node outflow station location, provides an overview of water law and process within each state, briefly covers compacts and court decrees that are in effect, and summarizes state-issued water rights for some states. The MBSA database is perhaps the most extensive compilation of water use information available for the Missouri River Basin.

OBSERVATIONS AND RECOMMENDATIONS

1. Final irrigated acres contained in the database may for certain areas vary from the figures made available earlier to Agricultural Work Group members. Those differences come from adjustments made to reflect state preferences primarily in Nebraska, Wyoming and Kansas. The opportunity to review these changes was limited, and all work group members were not asked to concur with them. therefore, minor disagreements in irrigated acres between state and federal agencies may still exist in certain areas.
   It is recommended that these differences be cleared up at the first update of the Water Accounting System.
2. It is recommended that as a part of the first update of the Water Accounting System, the Basic Information Archive System be developed into a computerized data storage and retrieval system as an auxiliary system to the MBSA database.
3. It is recommended that the MBSA Board seek out, and provide assistance through funding, a remote sensing project that would provide data on irrigated lands in those areas where such techniques are proven. Special emphasis for such a project should be given to areas that are controversial regarding number of acres irrigated.
4. It is recommended that the MBSA Board provide funding for a cooperative state-federal update of the MRB Water Accounting System beginning in 1984.







MONTANA

WYOMING

CANADA

UNITED STATES

NORTH DAKOTA

SOUTH DAKOTA

MINNESOTA

Node Basins
Missouri River Basin
Water Accounting System

- Missouri River Basin Boundary
- Node Basin Boundary
- 100100 Node Basin Number
- 01 Water Import, Export, or Node Basin Transfer
- 1-4 Data Base Gage Number
- ▲ Node Basin Outflow Point

N

12 0 12 24 36 48

GRAPHIC SCALE
in miles

WYOMING

COLORADO

GLENDO RESERVOIR

PATHFINDER RESERVOIR

SEMINOE RESERVOIR

15

20

21a

21b

21c

16b

16d

16c

17

27

JANUARY 1983
MISSOURI BASIN STATES ASSOCIATION

NEBRASKA

IOWA

KANSAS

MISSOURI

Location Map